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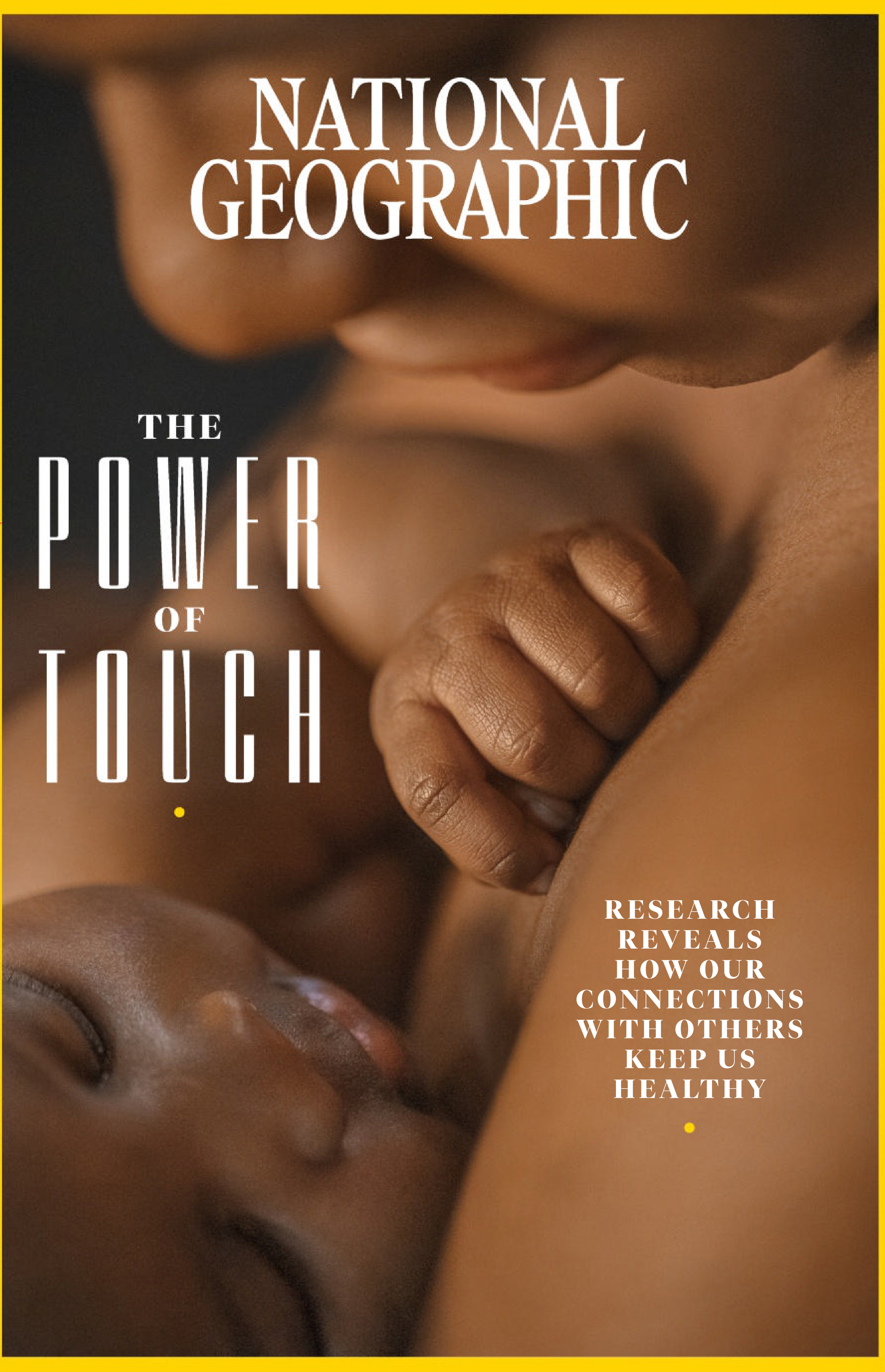

NATIONAL GEOGRAPHIC

THE POWER OF TOUCH

RESEARCH REVEALS HOW OUR CONNECTIONS WITH OTHERS KEEP US HEALTHY

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Davinia James-Stewart cuddles three-month-old daughter Harper. "My life has been pockets of love," and touch is one way of passing the love along, says James-Stewart, who was raised by adoptive parents after her birth mother's death.

LYNN JOHNSON

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Transforming Trash Into Protest Art
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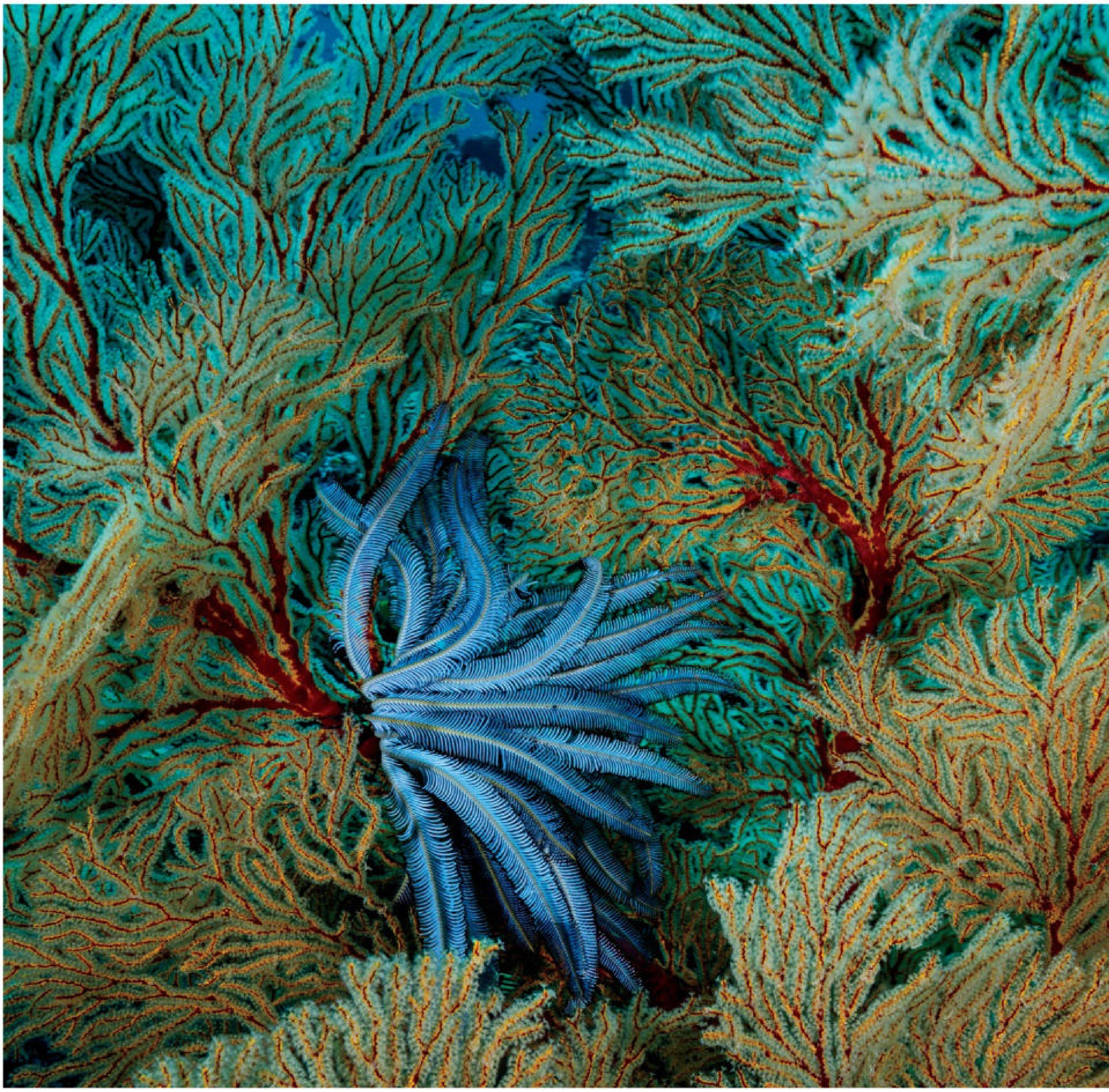

FEATURES

The Power of Touch
We all need it, for happiness and health. But what exactly is there in touch that makes it so important? Scientists, engineers, doctors, and research volunteers are pushing boundaries in an effort to understand this most enigmatic of the senses—and to return touch to people who have lost it.
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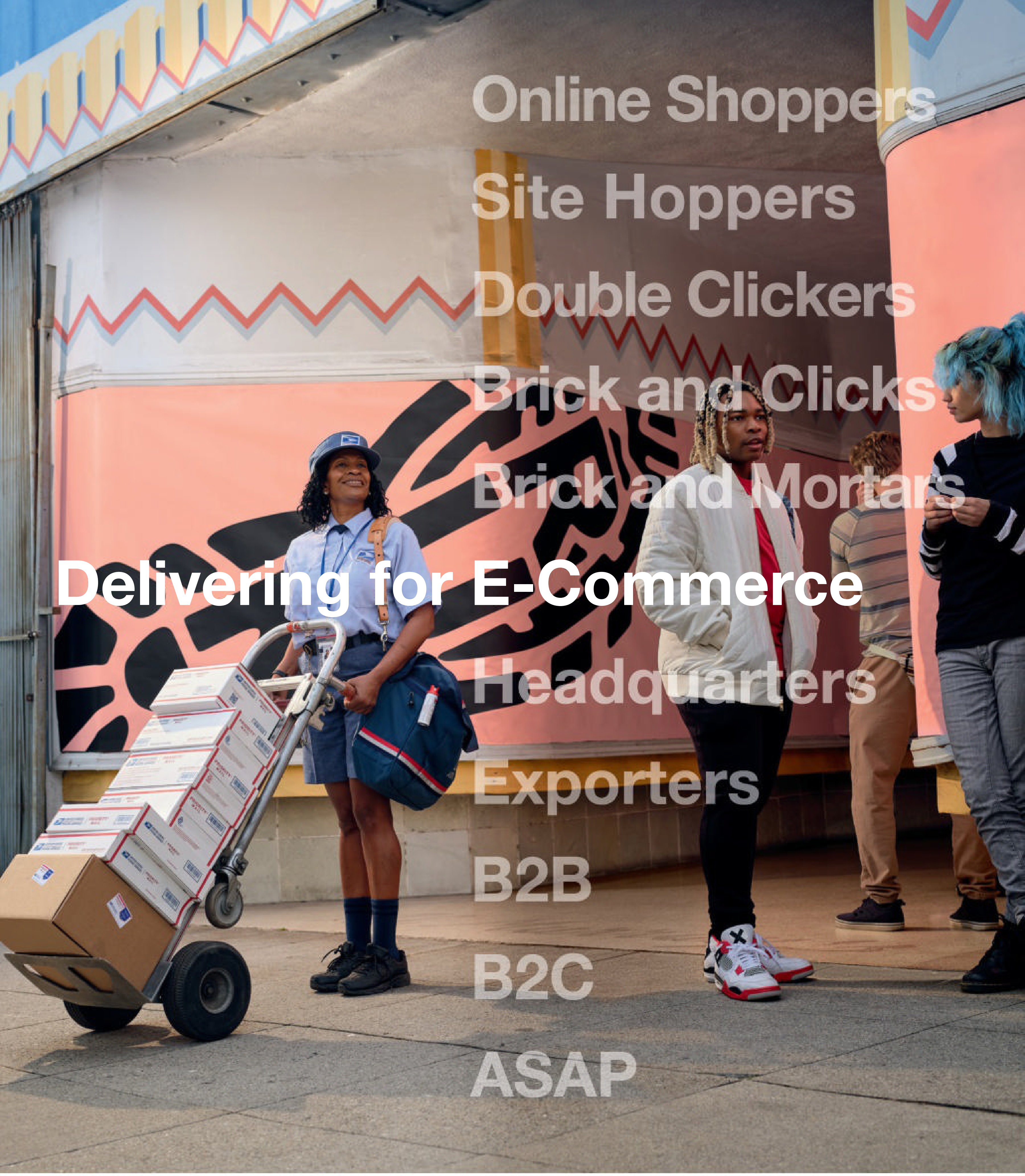
ABOVE: Gorgonian corals thrive in the Philippines' Tubbataha Reefs Natural Park. Though 374 square miles of the Sulu Sea are protected here, dangers still loom.



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Delivering for America

THE POWER OF TOUCH

Connections That Keep Us Healthy

PHOTOGRAPH BY **LYNN JOHNSON**

Touch was an early casualty of the COVID-19 pandemic. People sharply curtailed contact—especially indoors. But as cases fell and vaccinations rose, public gatherings picked up. At a school last August in Andria, Italy, students met outside in small groups to play "a game where they had to identify classmates by touch alone," says photographer Lynn Johnson.

WE EXPERIENCE THE WORLD through our senses: touch, sight, hearing, smell, and taste.

Among the five, the sense of touch is singularly important, a growing body of research confirms. As contributing writer Cynthia Gorney explains in this month's cover story, "Human beings require the physical presence of others, the comforting touch of others, in order to stay healthy."

At the School for Creativity in Andria, Italy, students learn that lesson at an early age. "The culture of touch in that school is daily," says longtime *National Geographic* photographer Lynn Johnson. "Moment by moment. It's very physical. They're always hugging and kissing." In the photo above, the children play a game in which a blindfolded student tries to recognize a classmate just by touch. Invariably they got it right, Johnson says.

This cover story assignment required Johnson to show the power of touch with her images. To do that, she told me, she "went on a mission: to try to look for situations, for people, for whom touch is a critical part of their lives—their survival, their orientation in life."

That mission took her to Margaret Malarney and her family in Chagrin Falls, Ohio. (See page 68.) "I met Margaret when she was minimally conscious. I didn't see any response on her face," Johnson says. But over a series of visits spanning seven months, Johnson witnessed "the way the family physically loved her back to life. We don't know the science behind it; we don't know why." And yet, Johnson says, "we can believe that touch has such value."

Thank you for reading *National Geographic.*

David Brindley
Interim Editor in Chief

ATEM Mini Pro model shown.

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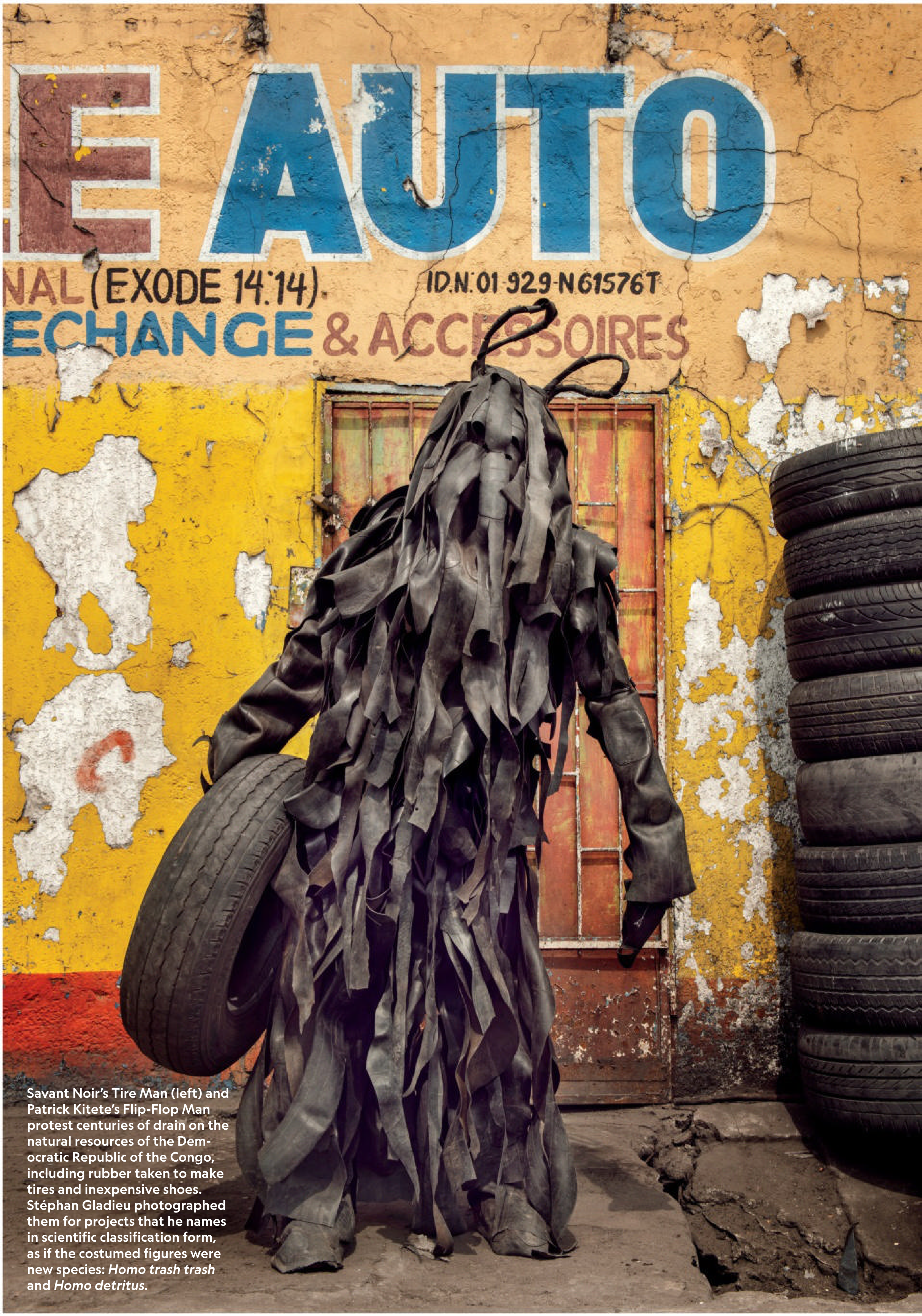
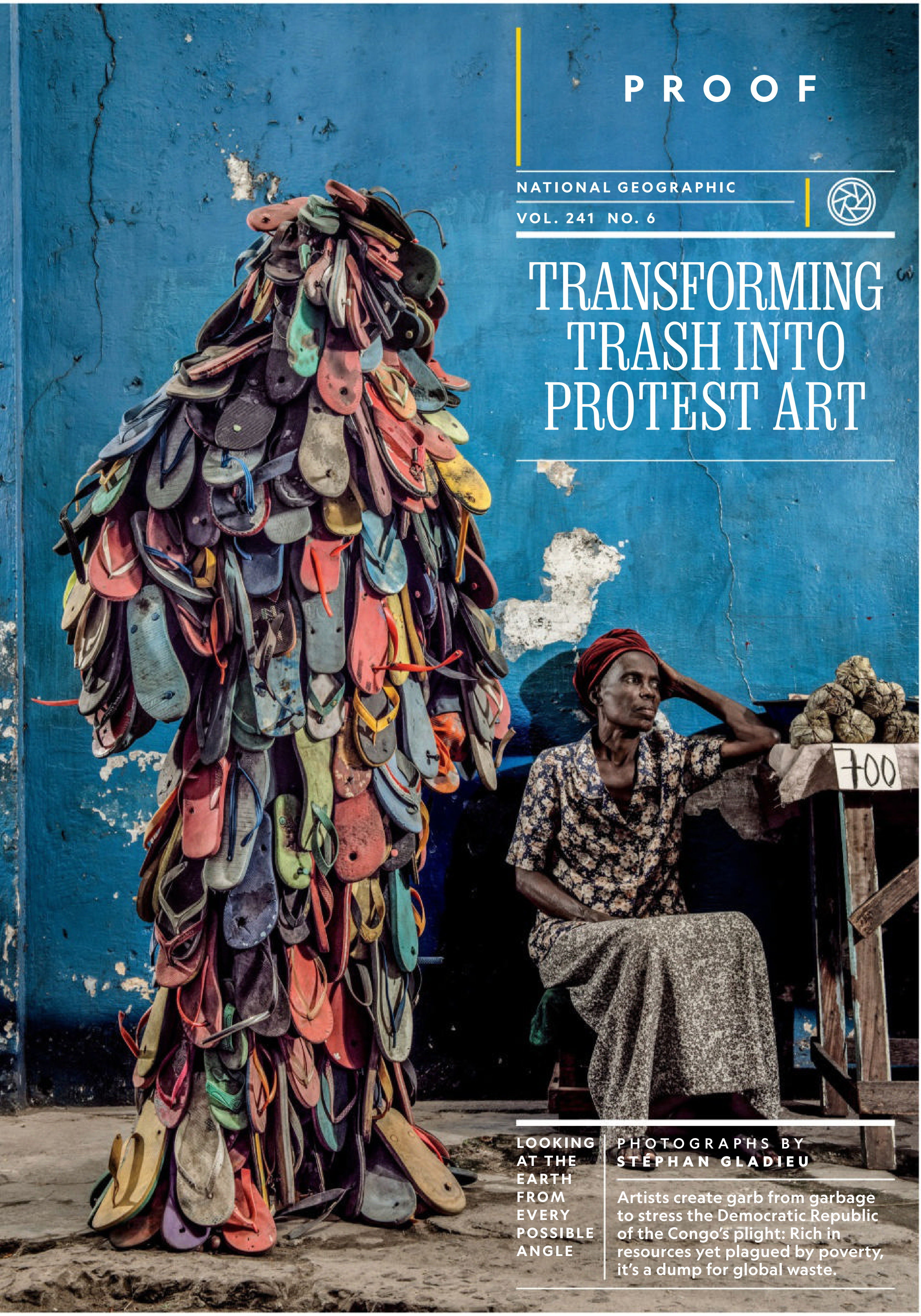


Savant Noir's Tire Man (left) and Patrick Kitete's Flip-Flop Man protest centuries of drain on the natural resources of the Democratic Republic of the Congo, including rubber taken to make tires and inexpensive shoes. Stéphan Gladieu photographed them for projects that he names in scientific classification form, as if the costumed figures were new species: *Homo trash trash* and *Homo detritus*.



PROOF

NATIONAL GEOGRAPHIC
VOL. 241 NO. 6

TRANSFORMING TRASH INTO PROTEST ART

LOOKING AT THE EARTH FROM EVERY POSSIBLE ANGLE

PHOTOGRAPHS BY
STÉPHAN GLADIEU

Artists create garb from garbage to stress the Democratic Republic of the Congo's plight: Rich in resources yet plagued by poverty, it's a dump for global waste.

PROOF

It started as a countercultural art movement in 2001.

After years studying at the Academy of Fine Arts, Kinshasa—following teachers' advice on creating work with "proper" materials, such as resin and plaster of paris—some students in the Democratic Republic of the Congo (DRC) decided to do something different. They created art with what was in their immediate environment, including tires, exhaust pipes, foam, plastic bottles, antennas, tins that had held milk or paint, feathers, CDs, rubber slippers, and other discarded items.

This work, the artists believed, felt familiar to a Congolese audience and spoke to a particularly egregious aspect of Congolese life: waste.

Waste generated locally by citizens. Waste foisted on the country by hyper-consumerist nations. Waste triggered by the endless extraction of resources from the DRC's earth, or the rapacious collection of the same above land.

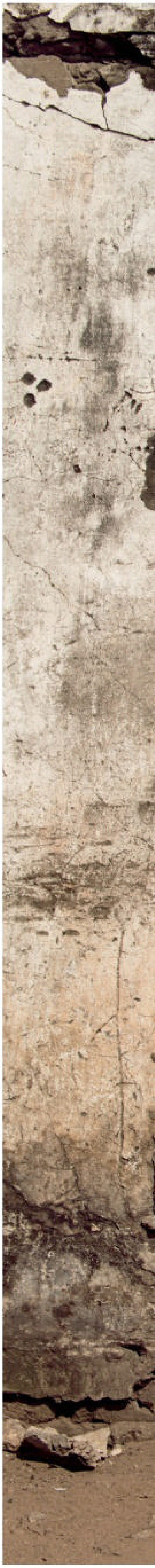
In Kinshasa, gutters are brimming with nonrecyclable plastic bottles. Markets are awash with second- and third-hand goods, castoffs from high-income countries and, at a quickening pace, China. In areas where international companies mine for cobalt—a precious component of smartphone batteries—frequent discharges contaminate river systems and surrounding life.

By repurposing waste to create sculpture and performance art, the artists wanted to dial up the public's acuity toward an ongoing emergency. In 2015 they laid the groundwork for a collective to institutionalize the art: Ndaku Ya Life Is Beautiful, led by Eddy Ekete. A Kinshasa-born artist and social activist, Ekete also founded the KinAct festival, an annual showcase for the provocative creations. Increasingly, for the artists, the waste provides an opening to comment on fraught sociopolitical issues.

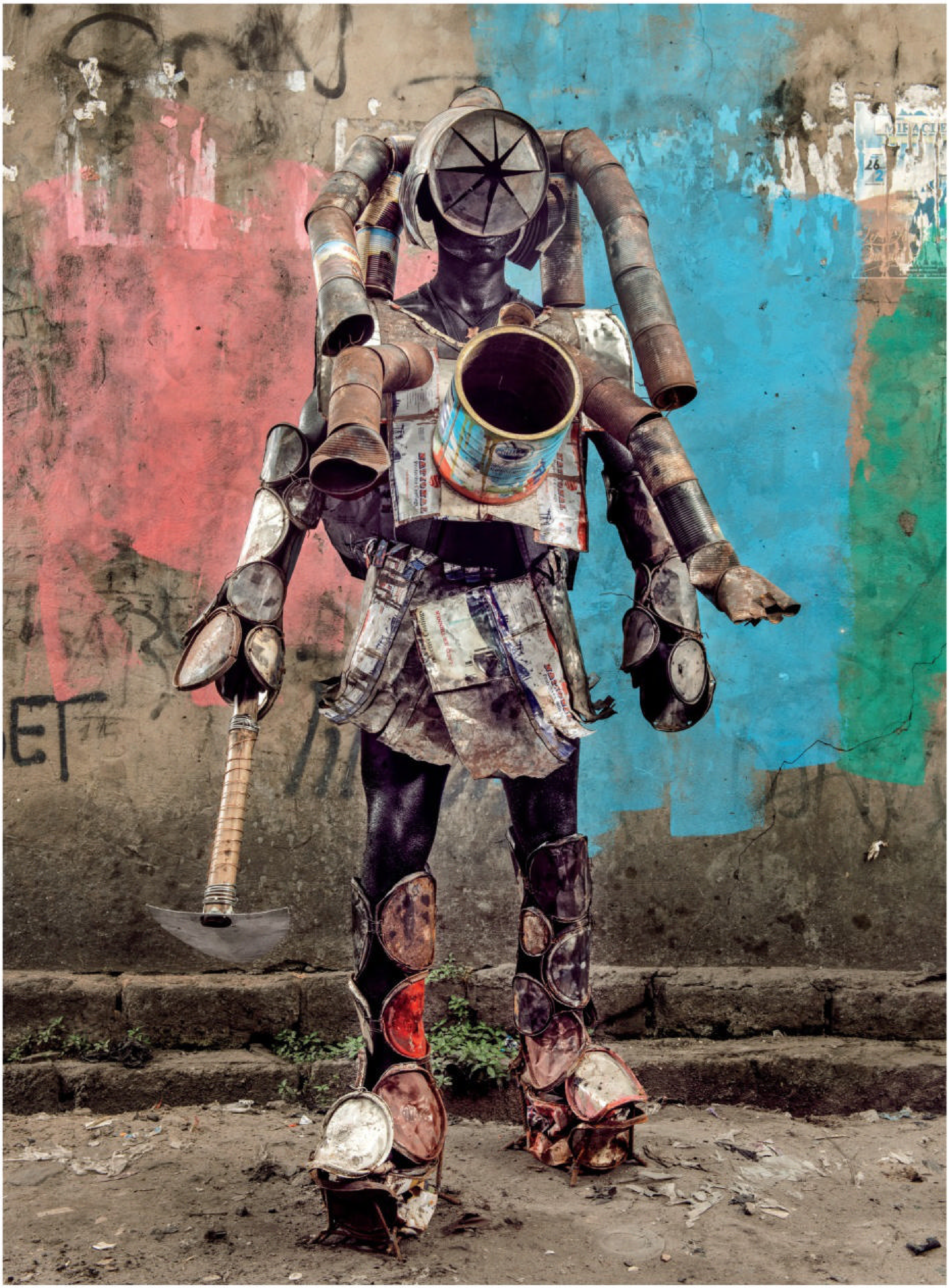
Robot Annonce, a wearable sculpture by Jared Kalenga, is made of broken radio parts. It seeks to raise awareness about the ever spreading reach of fake news.

Femme Électrique, Falonne Mambu's creation made of electric wires, is double-edged. It speaks to the paucity of electric power service in the DRC and, simultaneously, what goes on in the dark: sexual assaults, kidnappings. Mambu's inspiration for the work was drawn from periods in her life when she was homeless.

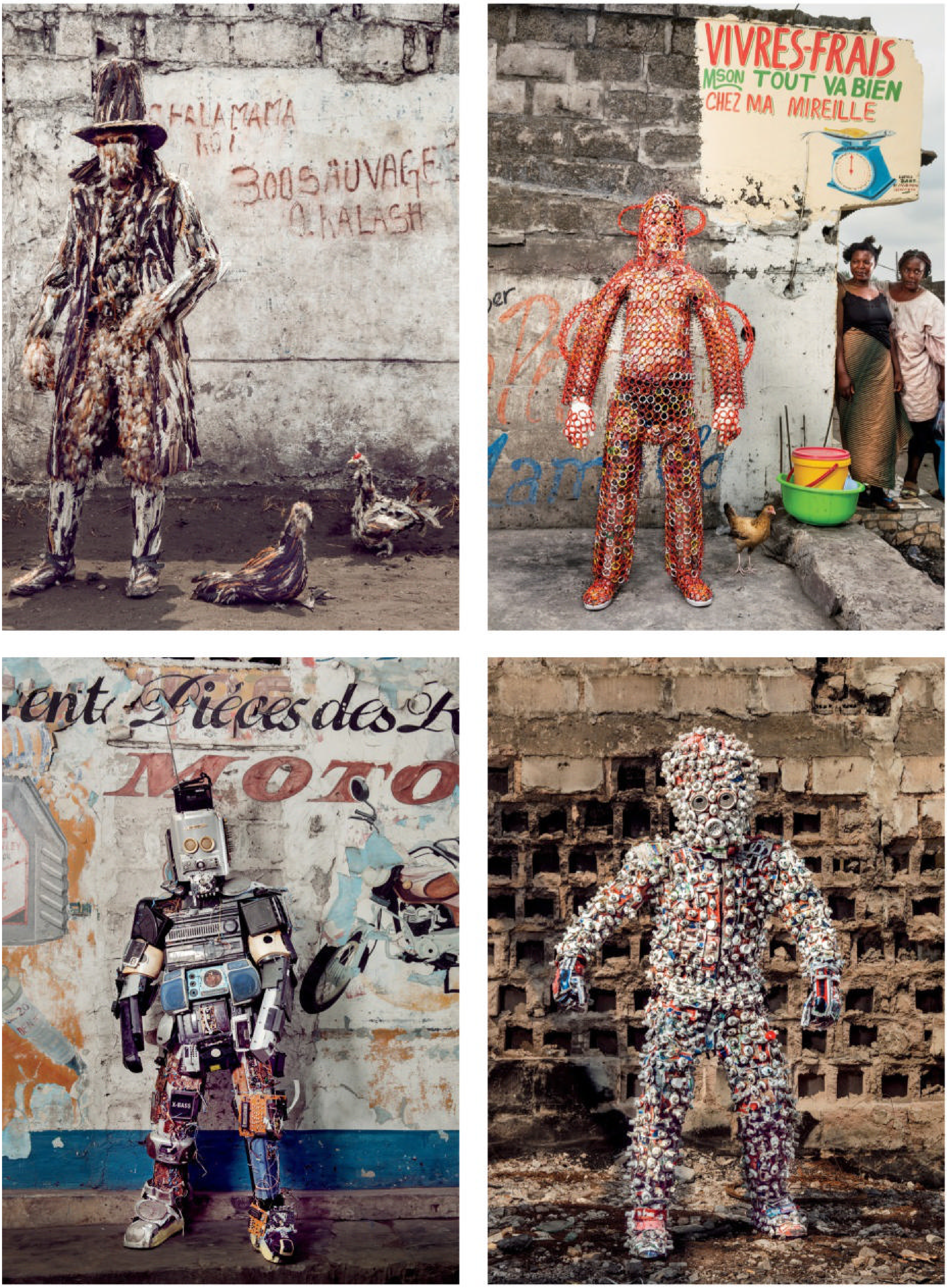
These socially conscious creators who turn refuse into protest art "are out here pushing limits," says Yvon Edoumou, founder of Kinshasa's Galerie Malabo. "We don't see a lot of that." —AYODEJI ROTINWA



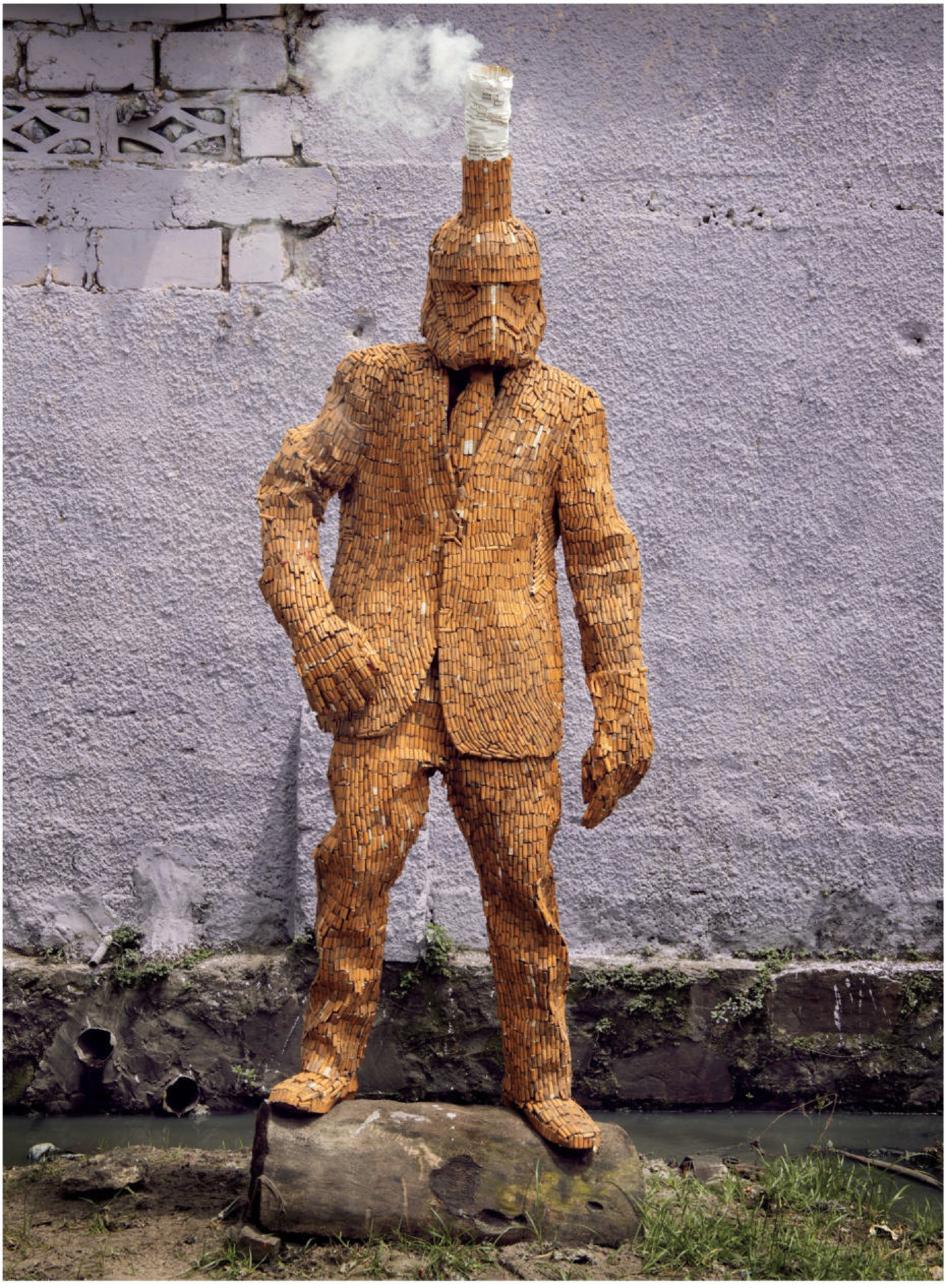
For several years, Gladieu has photographed Kinshasan artists wearing attire they create from rubbish—here, Shaka Fumu Kabaka dresses as Razor Man. At first reluctant to take the photo, Gladieu says he couldn't "deny the reality" of the artist's chosen medium: The suit is made of razor blades, which youth gang members use to ritually cut their initiates.



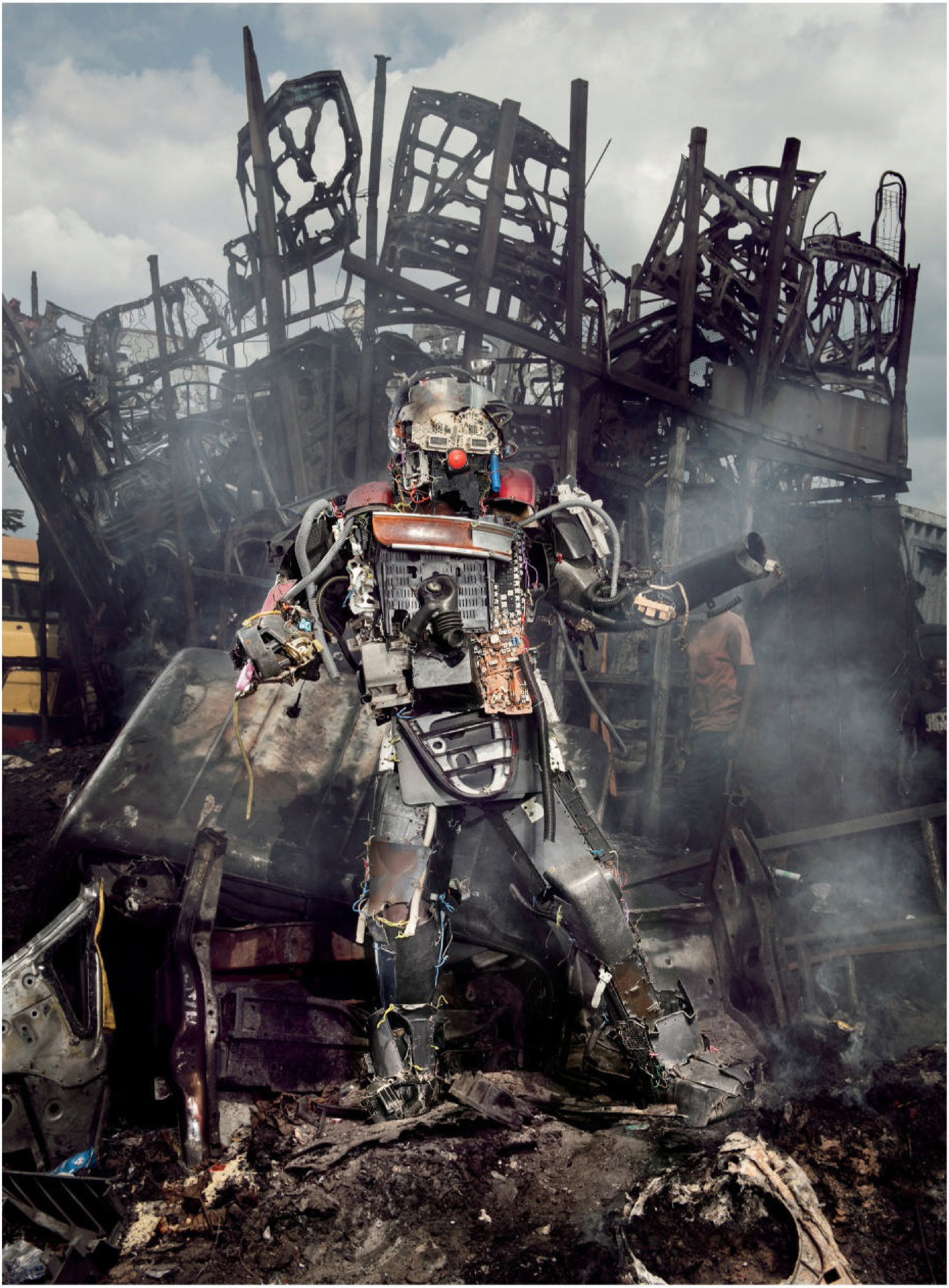
Mvunzi Muteba, Jr., said he designed his character, Tin Can, to raise Africans' awareness of how multinationals' presence has affected Africa. Despite the continent's riches, he says, "Africans still remain poor. They expect help from foreigners," but he insists that multinationals, in fact, come to Africa "to steal, create conflicts, [and] finance armed groups."



Artists ascribe meaning to their materials. Clockwise from top left: Savant Noir puts feathers, which invoke ancestors' aid, on a Western-style suit mocking rampant consumerism. Arnold Etabe uses plastic rings, and Shaka Fumu Kabaka toothpaste tubes, to represent viruses. Jared Kalenga's robot, made of radio parts, warns of misinformation in the media.



Kilomboshi Pape Noir turned cigarette waste into the figure of Butt Man, Gladieu says, as a reminder "that although the butt is very small, it is still very polluting"—full of toxins, such as lead, formaldehyde, and arsenic, and slow to decompose.



Making a figure out of automobile parts was Precy Numbi's way of protesting the millions of "garbage cars" imported into Africa every year—secondhand vehicles that discourage the growth of the continent's own auto industry.

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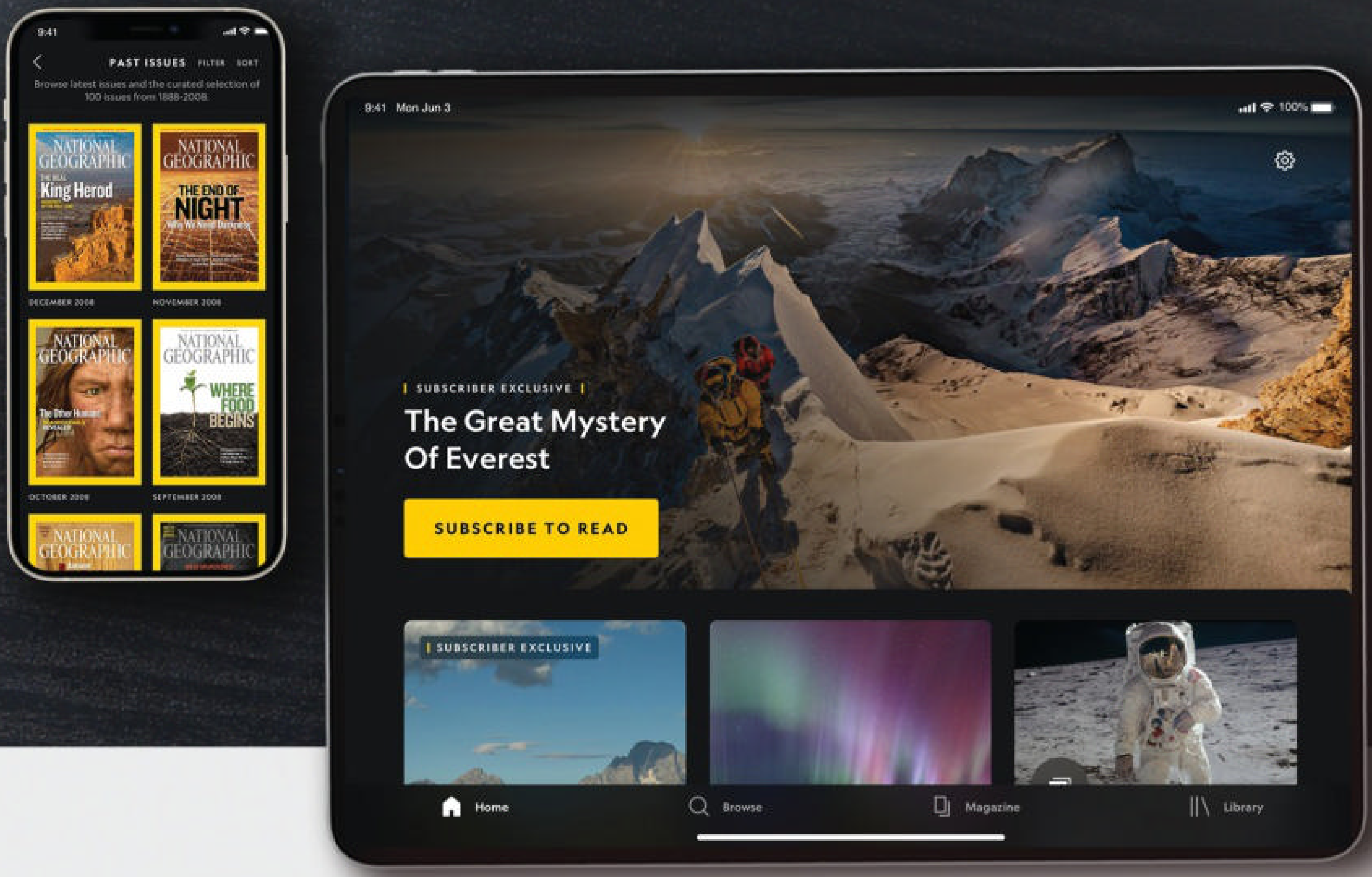

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IN THIS SECTION
Well-Built Water Lilies
Trekking Nepal Crags
Horseshoes Get Lucky
Testing a Cave's Depths

ILLUMINATING THE MYSTERIES—AND WONDERS—ALL AROUND US EVERY DAY
NATIONAL GEOGRAPHIC | **VOL. 241 NO. 6**

How the Midwest Is Latin American

BIG EXTENDED FAMILIES. SMALL-TOWN HEART. TIES TO THE LAND, TO NEIGHBORS, TO HOME. HAVE YOU LIVED HERE BEFORE? NO, AND YES.

BY **DAISY HERNÁNDEZ**

I

I WAS ORDERING A BURGER in Cincinnati the first time I began to sense that the Midwest was somehow familiar to me, which is to say that the Midwest was somehow Latin American.

It was a Saturday afternoon, pre-COVID, and people crowded the tables at Zip's Cafe, a small restaurant whose interior was as dark as it probably had been the first time its doors opened in the 1920s. The waitress wanted to know if someone would be joining me. No, I said, slightly annoyed because I had grown up with a mother and three aunties, all from Colombia, who did not believe that anyone, let alone a woman, should do anything alone.

The waitress did not notice my sigh. Distracted with full tables, she took my order and moved on—and for some reason, perhaps since I was alone and thinking of my mother, it seemed that when the waitress walked away, a curtain parted before me. The classic burger joint came into focus. There were

THE IMAGE OF FLIGHT IS SO DOMINANT THAT I HAD FORGOTTEN ITS OPPOSITE: PEOPLE *STAY* IN THE MIDWEST. THEY VALUE HAVING THEIR GRANDPARENTS CLOSE BY, THE COUSINS DOWN THE BLOCK OR ACROSS TOWN.

probably fewer than two dozen tables, and every seat was occupied not with friends or drinking buddies but with families. Teenagers bantered with grandparents, and a boy barely out of diapers lunged for a plate of french fries. At one table, a mother measured out a few ounces of soda for a child while talking with a woman who appeared to be her mother. At the tables, in other words, were intergenerational families—something I usually see in the United States only in immigrant communities.

I REMEMBER HOW A FRIEND raised in southwestern Ohio once described her childhood: surrounded by cousins and aunts and grandparents, in a close-knit tribe of Black folks who loved, and frequently gathered at, the large tract of land on which her great-great-grandparents had built the family home.

As I listened to her, I almost said, *It sounds like you grew up Latino.* But I held my tongue, as I had moved only recently to the Midwest for a university teaching job and knew nothing of the region.

My immigrant family had never lived west of the Hackensack River in northern New Jersey. They had embarked upon one enormous migration in the 1960s and '70s—my mother and three aunties from Colombia, my father from Cuba, an uncle from Peru—and upon arrival in the Garden State, they stopped. For them, the map of the United States ended just beyond where we lived. They never ventured into the Midwest, because every penny went toward the mortgage. And when my parents moved in their 60s to South Florida, they again settled in a working-class, mostly Spanish-speaking neighborhood.

When I ended up in Ohio, then, I began reporting on the Midwest, for my parents, my aunties—myself. I would tell my mother how my white students grew up in small towns here that once revolved around agriculture, and although none of the relatives now worked on farms, the families stayed: three generations, sometimes more, within a few blocks of one another, and church together every Sunday.

The same was true for my Black neighbors. They had been here for generations. One grandfather came to mow the lawn every week and see his grandchildren. The youngsters who flocked to multiple houses on our street were not friends but cousins. As one mother explained to me, "My sister and I take turns. I get all of them this weekend, so she gets a break."

My neighbor hauled her children to barbecues and my students wrote about their hometowns, and I remembered my own extended Latinx family in Jersey and how none of us left the house alone. We had one car, and into it we packed everyone: my sister and me, the aunties, the uncles, and if my *abuela* had been in the States, she would have been squeezed in too. We descended on local parks and house parties, one tiny tornado of a family, the Spanish bursting around us. Like my students and my neighbors' children, I spent summers playing tag, inventing stories, and listening to the women gossip. Our lives were insular, the kind of lives easily mocked in independent films and comedy skits, but they were family oriented.

This deep attachment to family in the Midwest surprised me, because by the time I moved here, I knew that the picture of the region offered in headlines was one of departures. People have been fleeing small towns in this part of the country for decades, seeking the jobs and connections large cities can offer.

The image of flight is so dominant that I had forgotten its opposite: People *stay* in the Midwest. They value having their grandparents close by, the cousins down the block or across town, the old high school friends nearby. They have a relationship with the land and small towns and each other that is complicated and that those of us who are outsiders fail to appreciate. It is a region of the country experiencing another change now that the COVID-19 pandemic has brought back some of those who once left, as well as those who want to escape city life with all its proximities.

MAYBE IT IS THIS TENSION—the departures, the returns, the decision to stay, a constant reference to migration—that also makes the Midwest familiar to me. My students are acutely aware of what the region offers them and how it fails them. It's the same way that my parents and their immigrant friends talk about Latin America. No one ever wanted to leave home. There were always stories about the brother who chose to stay in Colombia, the cousin who didn't get out of Cuba in time. And there was always talk about work. They left for work. They came for work. Now I read those stories, but they're from my students about Ohio, Michigan, and Wisconsin.

In the creative nonfiction classes I teach, students writing about home often pen essays about small towns that were promised bright futures when oil and gas companies arrived with jobs in fracking. A decade later, people in the Ohio Valley have seen jobs, incomes, and even population numbers drop, but the students do not write about statistics. They tell of how fracking changed the color of the skies. They write about fathers who toil in warehouses. One

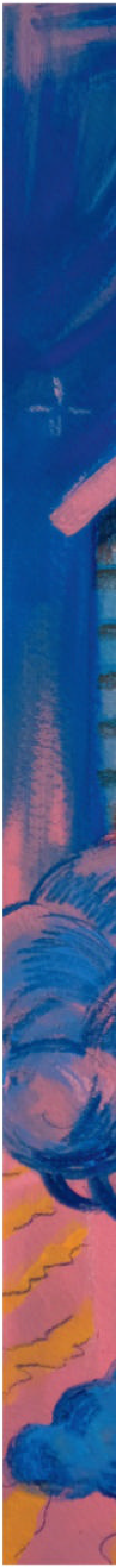

ILLUSTRATION: MARLY GALLARDO

undergrad penned an entire essay about the parking lot in her hometown, where even people in their 20s congregate at all hours of the day because the town can make no other promises at the moment.

As a child among Latin American families, I often would hear women slip references to tragedies into the folds of their stories, and the same happens with my students. A murder at a local hotel, a murder in their family—both are tucked into a phrase or two in a longer essay. Sometimes students mention the Great Recession: job losses for their parents and college savings wiped out. One student alludes to a glass pipe; most, however, say nothing about the meth epidemic sweeping the region. The one time a student braved an essay about discovering his mother's drug addiction, the students rallied around him, and in a secret ballot whose results only I saw, they voted his essay the best one of the semester.

I make a point of teaching the works of LGBTQ writers, in part because being queer in the Midwest is a little like being queer in a Latinx family. It's hard. My heart tugs in a particular way when a student comes out to me or when they tell me they want to come out to their families. In my early 20s, I hopped on public transit and an hour later disembarked in New York City with its lesbian bars and gay bookstores. My LGBTQ students don't have that. They have each other and their close-knit families and communities. So my initial questions are always about exile. Will you get kicked out? Do you need a place to stay? Who is your support circle?

Students, both straight and queer, often ask me, in their own way, how to write about home without hurting anyone. "I feel so guilty," they confess in reflections on writing about family and the Midwest.

I turn to the Ohio writer Toni Morrison, who said she wrote her first novel because it was the book she wanted to read. I tell my students: You have to write what you want to read. But often they look at me in a daze, measuring the weight of their wants against those of their families and their hometowns. I urge them to at least write a secret draft, and I take comfort in knowing that one day they will be able to write with more ease. I have no doubt they will write about this place, about home, in much the same way that I keep writing about mine. □

Daisy Hernández is an associate professor in the creative writing program at Miami University in Ohio. She won a top 2022 PEN America Literary Award for her book *The Kissing Bug: A True Story of a Family, an Insect, and a Nation's Neglect of a Deadly Disease.*

STUDENTS OFTEN ASK ME HOW TO WRITE ABOUT HOME WITHOUT HURTING ANYONE. I TAKE COMFORT IN KNOWING THAT ONE DAY THEY WILL BE ABLE TO WRITE WITH MORE EASE.

Excerpts from essays by students in Daisy Hernández's graduate creative nonfiction classes

More tired than the devil on a Sunday, my pap says, grabs green pepper seeds from his Carhartt pocket, tears the packet with teeth and dumps them into dirt trenches, reaches for the spray bottle of water and oil and old crushed multivitamins he calls miracle grow, not the brand name kind but the grandpa kind. It's green peppers now but it was kale and spinach before, tomatoes earlier in the summer.

The hillside garden of my grandparents' house grows food for canning, food for the deer they named Garcia, food to eat right out of the dirt after a drink from the hose. He sprays the seeds three times, kicks earth over with the side of a boot, points his eyes up to the sky and watches thick black clouds suffocate the sun, says something about getting in early and now the day is wasted or something similar, but I don't remember and he didn't clarify beyond a paint stick stuck in the mud to mark where he stopped planting. —MADISON KROB

One bright afternoon when I was in elementary school, my mom and I drove from our trailer park down to the Save A Lot discount grocery store with two soup cans in a plastic bag. At the service desk, my mom told the woman wearing the red uniform vest, "I bought these soups here last week. See?" She pulled the cans, now empty, out of the bag and set them on the counter. "They're labeled VEGETABLE SOUP. But I opened one and it wasn't vegetable at all. It's something different, I couldn't tell what. I tried the other can and it was the same."

We came for a refund on two 50-cent cans of generic soup. She had the receipt, but this was the only store in town selling brandless soup like this. They gave us our money back, and we bought more soup. That money wasn't going to pay the lot rent, but it did cover two solid meals.

When one bad thing happens to poor people, more is always on the way. —AMY BAILEY

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Call it a net win for marine life

Attaching green-colored LEDs to fishing nets called gill nets greatly reduces the amount of marine life caught in them by accident, recent tests showed. Illuminated nets need less repairing because sea turtles, sharks, and other species can see and avoid them. The lights reduce bycatch deaths and don't hurt hauls of targeted fish. —HW

PLANT SCIENCE

THE HIDDEN STRENGTH OF GIANT WATER LILIES

THEY LOOK LIKE THE STUFF OF FAIRY TALES, BUT THEY'RE AS SOLID AS THE WORK OF ENGINEERS.

At up to 10 feet in diameter, the floating leaves of giant water lilies (genus *Victoria*) are the largest on Earth. They are found in South American waterways, where they thrive and crowd out other plants. Some are sturdy enough to support the weight of a small child—a concept that a new paper in *Science Advances* illustrates literally, with a photo of a tot curled up on a colossal leaf.

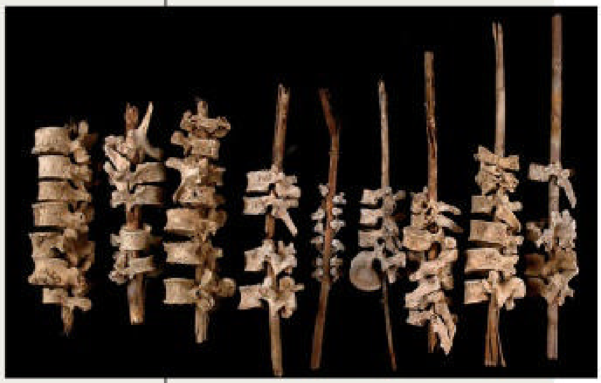
The species *V. cruziana,* though long known to be strong, was little understood until this study analyzed the underside of its leaf, where veins branch from one artery to the next in a geometric pattern. The rigid vascular architecture lets the plant spend less energy maintaining its size than other water lilies do; it provides, in the lead author's words, "high strength at low cost." The leaves' design could be adapted for other applications, such as floating platforms of solar panels in the ocean. —HICKS WOGAN

ARCHAEOLOGY

'Spines on sticks' honor Andean dead

Human vertebrae threaded on sticks may have been Indigenous people's attempts to reconstruct ancestors' bodies after graves were looted during Spanish rule in Peru some 500 years ago. Archaeologist Jacob Bongers studied 192 sets of the spine bones; he says dating shows they were first buried in the early 1500s and threaded on sticks about 40 years later. Descendants likely were "picking up the pieces of their dead and trying to put them back together" to restore the integrity of burials or bodies, he says.

—TOM METCALFE



PHOTOS (CLOCKWISE FROM LEFT): TONY WATSON, ALAMY STOCK PHOTO; NOAA FISHERIES; C. O'SHEA

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The trek to Nepal's Annapurna Base Camp gets

BY THE NUMBERS

26,545

HEIGHT OF ANNAPURNA I, IN FEET

13,550

ALTITUDE AT BASE CAMP, IN FEET

1977

YEAR THE ANNAPURNA REGION OPENED TO FOREIGN TREKKERS

Annapurna massif is home to the world's 10th tallest mountain, Annapurna I.

STEP INTO CLOUDS

close to Himalayan peaks—without Everest crowds.

BY **MARY ANNE POTTS** PHOTOGRAPH BY **EMILY POLAR**

COMPARED WITH THE MORE well-known trek to Everest's Base Camp, the hike to Annapurna's staging area offers lower elevations and fewer fellow trekkers. And unlike the popular Annapurna Circuit, it allows hikers to head deep into the Annapurna range, rather than going around its perimeter.

RETURN TO TOURISM

With some of the world's tallest summits, Nepal is a top trekking destination. A devastating 2015 earthquake and the pandemic have kept travelers away for the past few years, but now adventurers are coming back. "It feels intimate because the mountains feel really close," says photographer Emily Polar about the Annapurna Base Camp trek, which provides epic views of legendary peaks Dhaulagiri and Machapuchare.

THE ROUTE

The Annapurna Base Camp hike is a multiday, customizable loop best undertaken in spring or autumn, to avoid the monsoon rains. Hikers can fly into Kathmandu and make their way to Pokhara to start the trek either solo or with a guide. Local teahouses serve as the backbone of the trail experience and provide rustic accommodations, cultural connections, and food. All-you-can-eat *dal bhat,* Nepal's traditional savory lentil-and-rice dish, is especially popular with hungry trekkers.

THE LANDSCAPE

The route traverses a range of ecological zones, all located within Nepal's first designated conservation area and its largest protected region. It meanders through lush forest (you might glimpse a Nepal gray langur monkey here), past waterfalls and terraced fields, before emerging into a landscape of steep rock faces and snowcapped peaks. "You're hiking into a cirque, an amphitheater of mountains, that really frames the whole base camp," says Polar.

NGM MAPS

NUBEQA is a prescription medicine for men with prostate cancer that has not spread to other parts of the body and no longer responds to hormone therapy*

*Hormone therapy includes drug treatments or surgery that lowers testosterone.

Ask your doctor about NUBEQA **NUBEQA.com**

INDICATION

NUBEQA® (darolutamide) is a prescription medicine used to treat men with prostate cancer that has not spread to other parts of the body and no longer responds to a medical or surgical treatment that lowers testosterone.

It is not known if NUBEQA is safe and effective in women and children.

IMPORTANT SAFETY INFORMATION

NUBEQA can harm unborn babies and cause loss of pregnancy. Men with female partners who may become pregnant should use effective birth control (contraception) during treatment and for 1 week after the last dose of NUBEQA.

Before taking NUBEQA, tell your healthcare provider about all your medical conditions, including if you:

- Have kidney or liver problems.
- Have a partner who may become pregnant. Males who have female partners who may become pregnant should use effective birth control (contraception) during treatment and for 1 week after the last dose of NUBEQA. Talk with your healthcare provider about birth control methods.
- For women, tell your healthcare provider if you are:
  - pregnant or plan to become pregnant. NUBEQA can cause harm to your unborn baby and loss of pregnancy (miscarriage)
  - breastfeeding or plan to breastfeed. It is not known if NUBEQA passes into breast milk.

Even with rising PSA on hormone therapy[*]

NUBEQA HELPS YOU LIVE FOR WHAT YOU LOVE

In a clinical trial, **MEN LIVED 2X LONGER** **without their prostate cancer spreading to other parts of the body when they added NUBEQA to hormone therapy** (median[†] 3.4 years for NUBEQA + hormone therapy compared with 1.5 years for hormone therapy alone)

Adding NUBEQA also extended overall survival[‡] by lowering the risk of death by 31% compared with hormone therapy alone

Tell your healthcare provider about all the medicines you take, including prescription and over-the-counter medicines, vitamins, and herbal supplements. NUBEQA may affect the way other medicines work and other medicines may affect how NUBEQA works.

You should not start or stop any medicine without talking to your healthcare provider.

Most common side effects of NUBEQA include:

• Feeling more tired than usual • Arm, leg, hand, or foot pain • Rash • Decreased white blood cells (neutropenia) • Changes in tests that determine how your liver works (liver function tests)

NUBEQA may cause fertility problems in males, which may affect the ability to father children. Talk to your healthcare provider if you have concerns about fertility.

These are not all the possible side effects of NUBEQA. Call your doctor for medical advice about side effects. You may report side effects to the FDA at 1-800-FDA-1088 or www.fda.gov/medwatch.

[†] Median is the middle value in a set of numbers, not the average.

[‡] How long a person may live after diagnosis or starting a therapy.

Please see additional Important Safety Information on adjacent page and Important Facts About NUBEQA on next page.

NUBEQA®
(darolutamide) 300 mg tablets

IMPORTANT FACTS ABOUT NUBEQA® (darolutamide) tablets (new-BEH-Kah)

What is NUBEQA?

NUBEQA is a prescription medicine used to treat men with prostate cancer that has not spread to other parts of the body and no longer responds to a medical or surgical treatment that lowers testosterone. It is not known if NUBEQA is safe and effective in women and children.

What should I tell my healthcare provider before taking NUBEQA?

Tell your healthcare provider about all your medical conditions, including if you:

- Have kidney or liver problems
- Have a partner who may become pregnant. Males who have female partners who may become pregnant should use effective birth control (contraception) during treatment and for 1 week after the last dose of NUBEQA. Talk with your healthcare provider about birth control methods
- For women: tell your healthcare provider if you:
  - are pregnant or plan to become pregnant. NUBEQA can cause harm to your unborn baby and loss of pregnancy (miscarriage)
  - are breastfeeding or plan to breastfeed. It is not known if NUBEQA passes into breast milk

Tell your healthcare provider about all the medicines you take, including prescription and over-the-counter medicines, vitamins, and herbal supplements.

NUBEQA may affect the way other medicines work and other medicines may affect how NUBEQA works.

You should not start or stop any medicine before you talk with the healthcare provider that prescribed NUBEQA.

How should I take NUBEQA?

- Take NUBEQA exactly as your healthcare provider tells you.
- Your healthcare provider may change your dose if needed.
- Take your prescribed dose of NUBEQA 2 times a day with food.
- Swallow NUBEQA tablets whole.
- If you are receiving gonadotropin-releasing hormone (GnRH) analog therapy, you should continue with this treatment during your treatment with NUBEQA unless you have had a surgery to lower the amount of testosterone in your body (surgical castration).
- If you miss a dose of NUBEQA, take your normal dose as soon as possible before your next scheduled dose. **Do not take 2 doses together to make up for a missed dose.**
- If you take more NUBEQA than prescribed, call your healthcare provider right away.

What are the possible side effects of NUBEQA?

- Feeling more tired than usual
- Arm, leg, hand, or foot pain
- Rash
- Decreased white blood cells (neutropenia)
- Changes in tests that determine how your liver works (liver function tests)

NUBEQA may cause fertility problems in males, which may affect the ability to father children. Talk to your healthcare provider if you have concerns about fertility.

Tell your healthcare provider if you have any side effect that bothers you or that does not go away.

These are not all the possible side effects of NUBEQA. Call your doctor for medical advice about side effects.

How should I store NUBEQA?

- Store NUBEQA at room temperature between 68°F to 77°F (20°C to 25°C).
- Keep the bottle tightly closed after you first open it.

Keep NUBEQA and all medicines out of the reach of children.

The information provided here is not comprehensive.

To learn more about NUBEQA:

- Talk to your healthcare provider or pharmacist
- Visit www.nubeqa.com to obtain the FDA-approved product labeling
- Call 1-888-842-2937

You may report side effects or quality complaints of products to the FDA by visiting www.fda.gov/medwatch, or call 1-800-FDA-1088.

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PLANET
POSSIBLE

For more stories about how to help the planet, go to *natgeo.com/planet*.

To keep unwanted guests out of your yard, try our nature-approved tips.

BY **CHRISTINA NUNEZ**

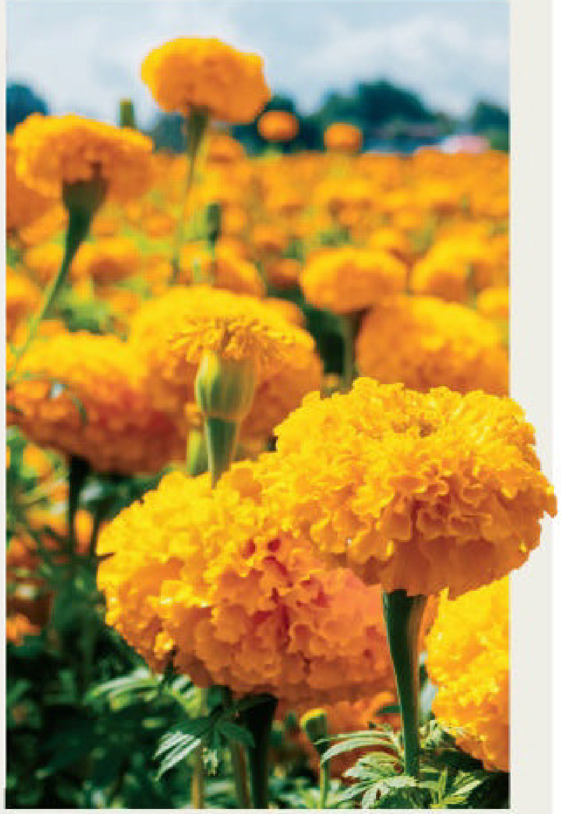
1

Debugging the patio
Many mosquito repellents are based on natural ingredients; oil of lemon eucalyptus is one that's effective, research suggests. Or try a cool way to deter bloodsuckers: Blow them off course with a fan. In a *Consumer Reports* test, a fan cut mosquito landings on those nearby by 45 to 65 percent. Airflow buffets the insects, which aren't strong fliers, and scatters the exhaled CO_2 that lures mosquitoes to their victims.

2

SEEDLING PROTECTION

APHIDS GENERALLY WON'T HARM HEALTHY, MATURE PLANTS, AND THEY'RE FOOD FOR BENEFICIAL INSECTS—BUT THEY CAN WEAKEN YOUNG PLANTS. KNOCK OFF APHIDS WITH YOUR FINGERS OR WATER, OR SPRAY THEM WITH INSECTICIDAL SOAP.



3

MARIGOLDS, YES OR NO?
Many gardeners swear by planting the brightly colored flowers as protective companions for tomato vines. Though the scientific backing for this idea is scant, one study found that French marigolds do help cut down on whiteflies. And marigolds certainly attract pollinators—so temper your expectations, but plant away.

4

NOT IN OUR GARDEN

Deer and rabbits can make quick work of plants such as hostas and petunias. Physical barriers like fences are best to keep the browsers out of your garden. But most are also deterred by pest-repellent sprays based on animal blood or raw eggs, for which DIY recipes can be found online.

PHOTOS (CLOCKWISE FROM TOP LEFT): GETTY IMAGES/SCIENCE PHOTO LIBRARY; ZOONAR GMBH/ALAMY STOCK PHOTO; KITTIKORN SITTHIPROM, EYEEM/GETTY IMAGES; GETTY IMAGES/JOHNER RF

WHEN SHE ATTRACTS HIM, AND HIM, AND HIM, AND ...

IT'S HIGH TIDE on the Delaware Bay, and Atlantic horseshoe crabs *(Limulus polyphemus)* are clambering ashore to mate. For this shield-shaped arthropod, assignations are typically a group affair: one female, one male, and a lot of male hangers-on.

The trysts sometimes begin underwater. A male angling for fatherhood uses his boxing glove–like front legs to clasp onto a female's abdomen and hitch a ride directly behind her through the surf. So situated, he stands ready to contribute sperm the moment she begins laying her eggs on the sand. However, "there's a lot more competition on the beach," says Jordan Zimmerman, a horseshoe crab biologist at Delaware's natural resources agency. For reasons still unknown to science, some females are so appealing that, even if they're already otherwise engaged, more males seek them out.

With spare studs in a polyamorous heap around her, the female releases her eggs. The attached mate deposits his sperm, and the third wheel—and fourth, fifth, and sixth—"pounces" to deposit his also, Zimmerman says. This waiting-in-the-wings technique can be surprisingly effective: Paternity tests have shown that satellite males sometimes father as many of the female's brood as the attached male.

Yes, mating is a battle. And after the animals spawn, ravenous shorebirds compete for the clutches of fertilized eggs. Yet after 450 million years, *L. polyphemus* is still here. —DINA FINE MARON

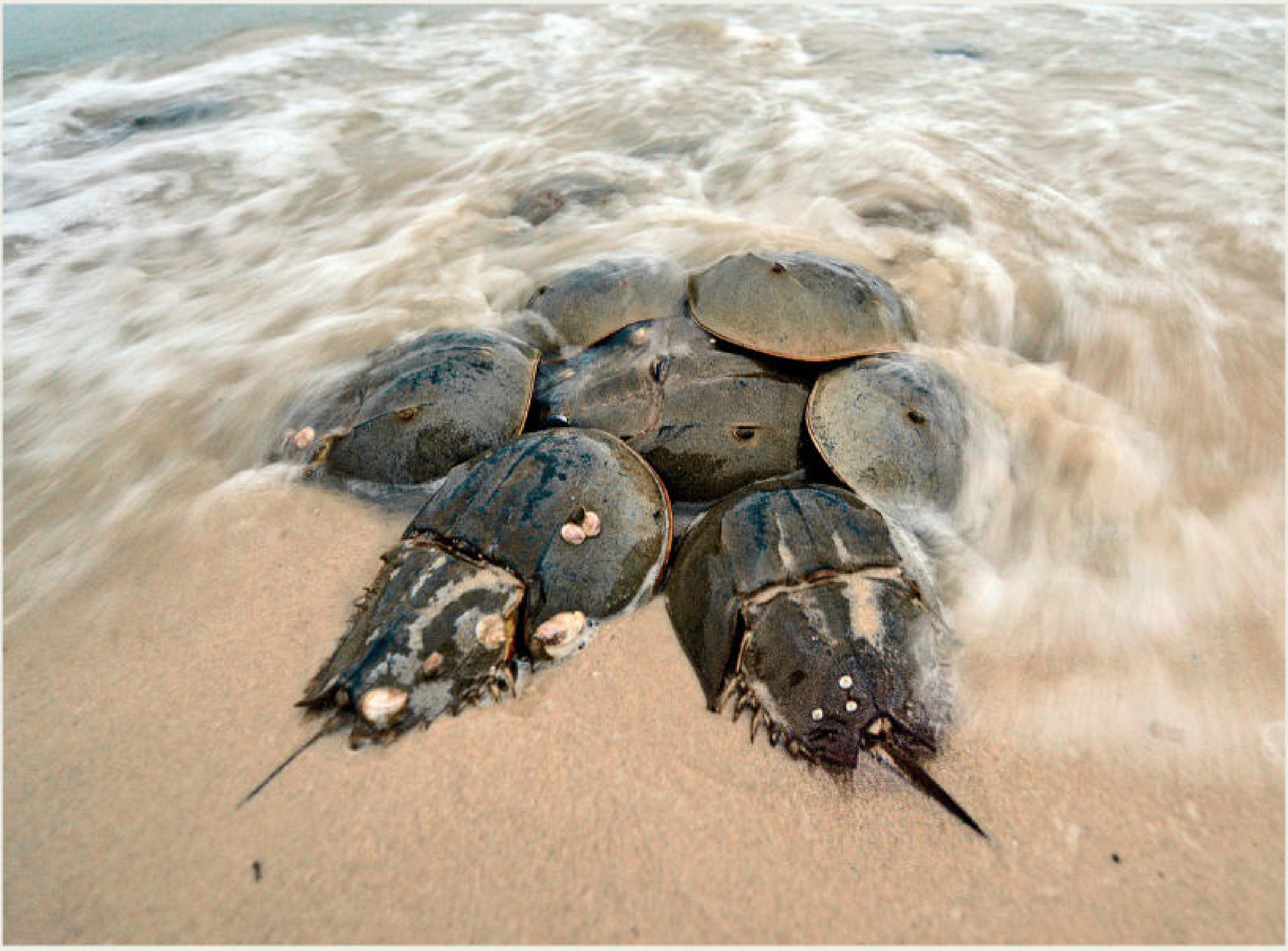
HABITAT/REGION

Atlantic horseshoe crabs are found on the U.S. coastline from New England to Florida and in Mexico. They're more closely related to scorpions and spiders than to crabs, despite their name, and eat mostly worms and mollusks.

OTHER FACTS

The biomedical industry catches about 500,000 U.S. horseshoe crabs annually and takes a portion of their toxin-sensitive blue blood to use in lab safety tests, including for COVID-19 vaccines. Most of them are returned to the water, but an estimated 15 to 30 percent don't survive.

Despite appearances, these animals don't sting. Their tails help them navigate and right themselves when overturned. If you see a hapless horseshoe crab on its back, biologist Jordan Zimmerman asks that you flip it over.



On the New Jersey side of Delaware Bay, Atlantic horseshoe crabs mate on the shallow sand coast.

PHOTO: HELMUT CORNELI, ALAMY STOCK PHOTO

TRAVEL WITH US THIS SUMMER

the catch me if you can
One Woman's Journey to Every Country in the World
JESSICA NABONGO

NATIONAL GEOGRAPHIC
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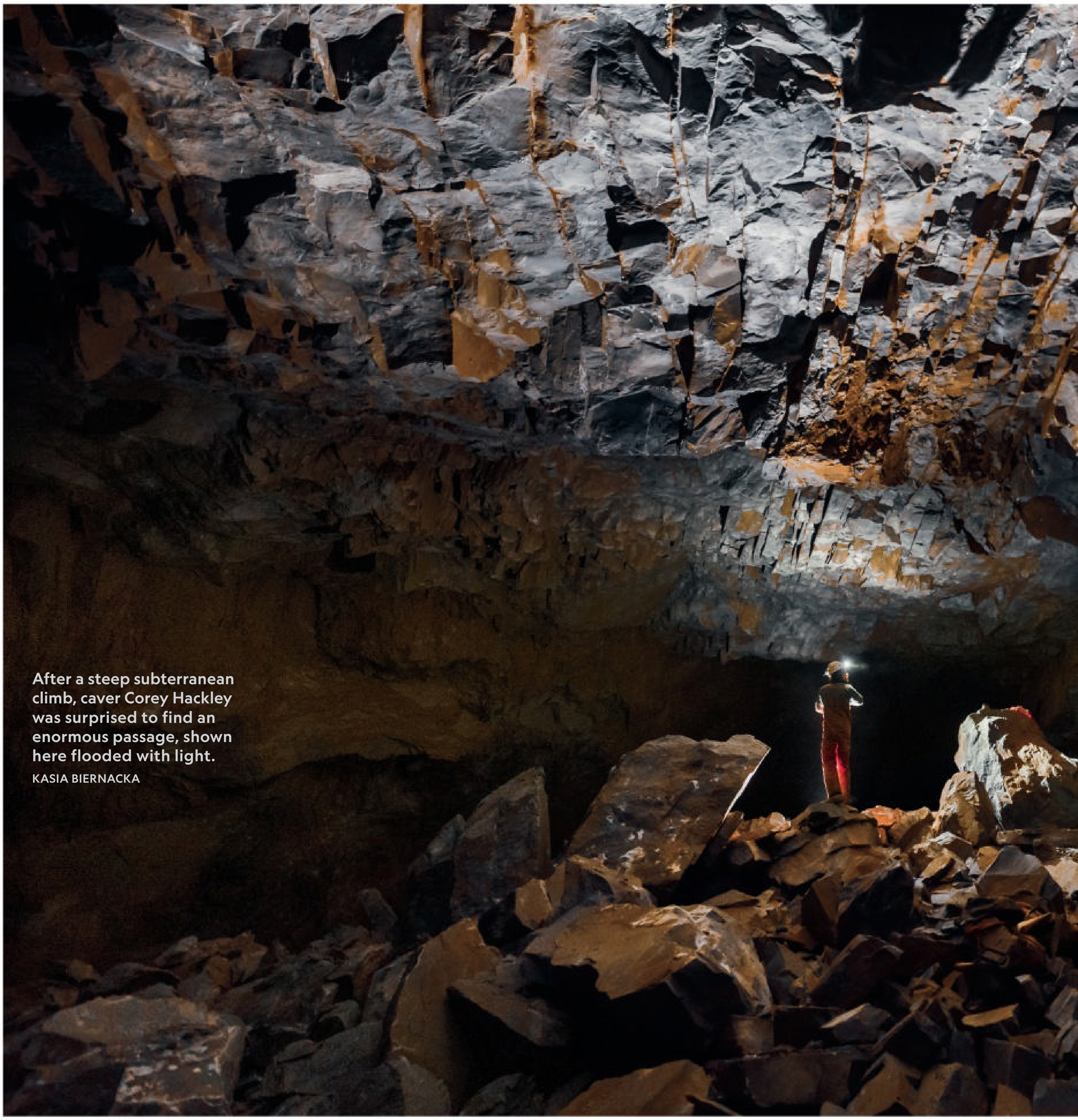

After a steep subterranean climb, caver Corey Hackley was surprised to find an enormous passage, shown here flooded with light.
KASIA BIERNACKA

Going Ever Deeper

FOR DECADES, HIGHLY SKILLED CAVERS HAVE COME TO MEXICO TO EXPLORE A LABYRINTH WITHIN A MOUNTAIN: CHEVE, WHICH MAY (OR MAY NOT) BE THE DEEPEST CAVE ON EARTH.

BY **MAYA WEI-HAAS**

ON A CLOUDLESS SPRING DAY in southern Mexico, I follow four cavers over a hill studded with pine trees, down 49 dirt steps, and across a grassy field. We approach a towering rock face on the side of a mountain so enormous that it's difficult to take in all at once. But what drew me here, along with 69 world-class cavers from nine countries, lies at its base.

Beyond a gash that cuts low across the rock face is Sistema Cheve—a cave with the potential to be the deepest on Earth.

As the geologic cathedral comes into full view, I hear a quiet expletive escape Corey Hackley, the caver just ahead of me. This is his fifth year exploring Cheve, and its grandeur still fills him with awe. "The scale of this place is unimaginable," says Hackley, who's been exploring caves since he was about 10. "It doesn't belong on Earth, in my mind."

Hackley has grown restless in the past few days, forced to linger in base camp for a precautionary COVID-19 quarantine. He calls the hubbub at the surface "suffocating"—a term some might apply to the confines of a cave. But for Hackley and the other cavers, the depths are anything but.

They're the last frontier of exploration.

In 1990, explorers dumped green dye in the stream flowing into Cheve's mouth. They discovered the colored water burbling out near the mountain's base, some 1.6 miles down from the cave's highest known entrance at the time. If a human could navigate the full length the water did, Cheve would be declared the deepest cave in the world, beating the current record holder—Veryovkina in Abkhazia, Georgia—by almost a quarter mile.

The tantalizing possibility has drawn explorers for decades, and this 2021 expedition was the biggest push yet. Under the leadership of National Geographic Explorer Bill Stone, the cast of cavers clocked more than 1,500 cumulative nights underground and discovered over 12 miles of unexplored passages.

I FIRST MEET STONE AFTER he's surfaced from more than two weeks underground, one of his many trips into Cheve since 1988. Imposing in height and demeanor, Stone asks if I've visited the cave yet. I tell him about tagging along with a member of his team.

I had shadowed Reilly Blackwell, who moves through Cheve with the sure-footedness of a dancer performing familiar steps. A mere 10 minutes into the cave, we'd arrived at Cheve's first series of precipitous drops, clipped into a section of the miles of rope the cavers had rigged, and down we'd gone. Blackwell's cheery calls had echoed out from the darkness as we'd scurried over fallen rocks and along scalloped walls until arriving at the base of Angel Falls, about a thousand feet deep. Just beyond lay the first of five camps the team had established at that time.

As I gush about that day's experiences to Stone, a sly look crosses his face. "That's just the tip of the iceberg," he says. "Camp One is kindergarten."

The cavers follow a multilevel labyrinth through the mountain’s underbelly. Carved by rivers over millions of years, some passages are big enough to fit a Boeing 747 plane; others are so tight the cavers can pass only while exhaling to compress their rib cages.

As Stone’s crew tests the limits of exploration, pushing toward record depths and gathering mapping data on the way, camaraderie and teamwork are essential. By the end of the 2021 season, the farthest and deepest camp lay 7.3 miles, or about a five-day trip, from the closest entrance. Only a select few work at that point. Others tend the miles of rigging or search for swifter and safer routes. And all must shuttle heavy packs with supplies and energy-dense foods to stock the camps. For every bite taken underground, Stone says, “a whole chain of people have paid for that in sweat.”

The one-hour special *Explorer: The Deepest Cave* premieres on May 30 at 10/9c on the National Geographic Channel and streaming on Disney+.

PEOPLE AT CHEVE give different reasons for their devotion to caving. Many are driven by an “insatiable curiosity,” Blackwell says. She and Hackley both use the word “compulsion” to describe their desire to seek new passages. But the search can be dispiriting.

Hackley and teammate Bev Shade recall a bleak moment in 2017 while hunting for a way through one cave section. It was named after a picturesque Mexican beach, but in reality—typical of cavers’ wry humor—it was a cramped cleft where water and mud pelted them from a hole in the ceiling. Hackley remembers Shade, covered in slop, turning to tell him, “Sometimes I wonder why I don’t have a different hobby, like bird-watching.”

Such moments forge indelible bonds between the cavers, evident in the laughter Hackley and Shade share while recounting their tale.

The strong community is a big part of what’s kept Shade involved for some 30 years, ever since she attended her first caving event at 16 in her hometown of Austin, Texas. She finds serenity underground too, “away from the chaos of everyday life.”

For many, caving also represents embracing life to the fullest. On a day trip to explore other entrances to Cheve, a trio of team members found a pit whose echo promised great depth, and eagerly lowered themselves as far as their rope allowed. They returned hours later, vibrating with excitement, and reported that beyond their reach were even more passages to explore. “This is why I do it, right there,” team member Mike Frazier declared.

Setting a record is almost beside the point, many of the cavers tell me. “There’s always going to be another deepest cave in the world,” Shade says. “We’re just all trying to do something together. Something that none of us could do by ourselves.” ◻

Maya Wei-Haas is a staff science writer at *National Geographic*.

Beyond Cheve’s Camp One, caver Mikołaj Harasimowicz navigates a challenging section named Salmon Ladders for its similarity to the obstacles salmon must surmount to swim upstream to spawn. PABLO DURANA

NGM MAPS

TRUTH ABOUT WEIGHT®
The cycle can be broken

Why do we eat?

For example,

Sometimes we eat because we're hungry.

Other times we eat for pleasure, even when we're not hungry.

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All day, your nervous system, which includes the brain, receives signals about your appetite from hormones that come from different parts of your body, like the stomach, intestines, and fat tissue. Both the brain and these appetite hormones contribute to what, why, and how much you eat. **But after we lose weight, changes in these appetite hormones can cause us to eat more, which may contribute to weight regain.** This can make it difficult to manage weight over time.

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NATIONAL GEOGRAPHIC

JUNE 2022

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FEATURES

96

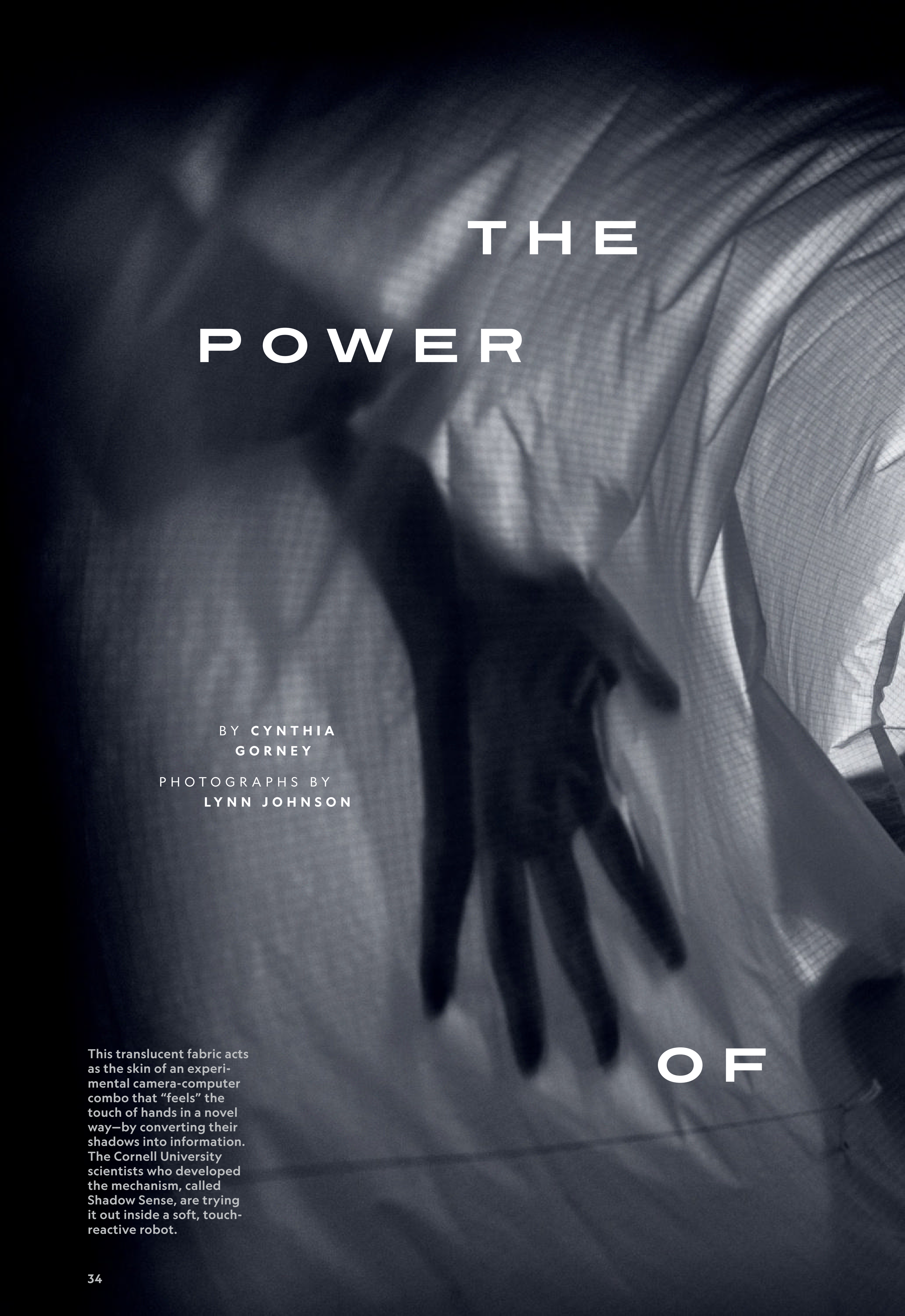
THANKS TO CAPTIVE BREEDING, NATIONAL ACCLAIM, AND AN INNATE SCRAPPINESS, THE IBERIAN LYNX HAS LEAPED TENFOLD IN POPULATION OVER THE PAST TWO DECADES.

PHOTO: SERGIO MARIJUÁN

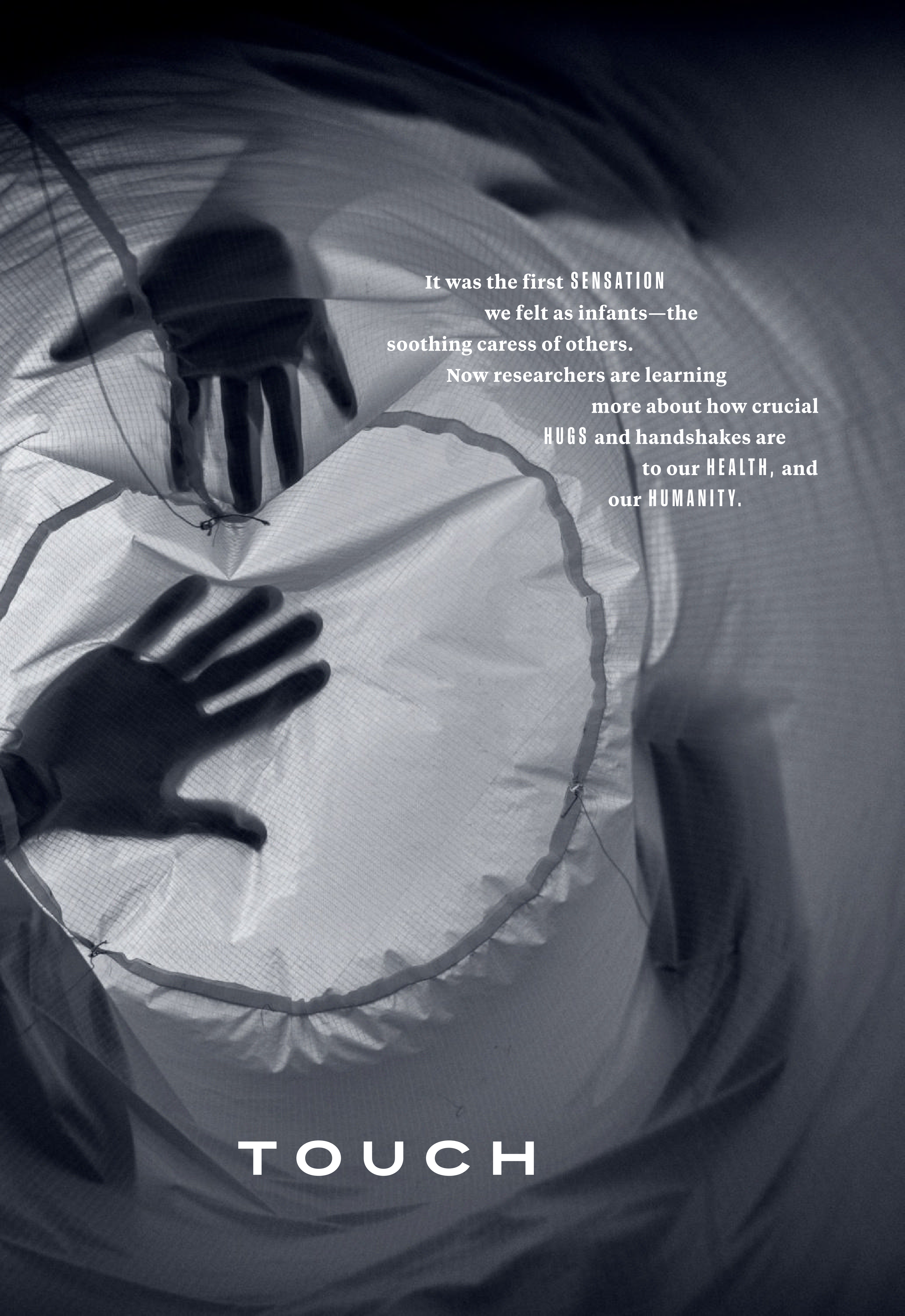
THE POWER OF

BY **CYNTHIA GORNEY**

PHOTOGRAPHS BY **LYNN JOHNSON**

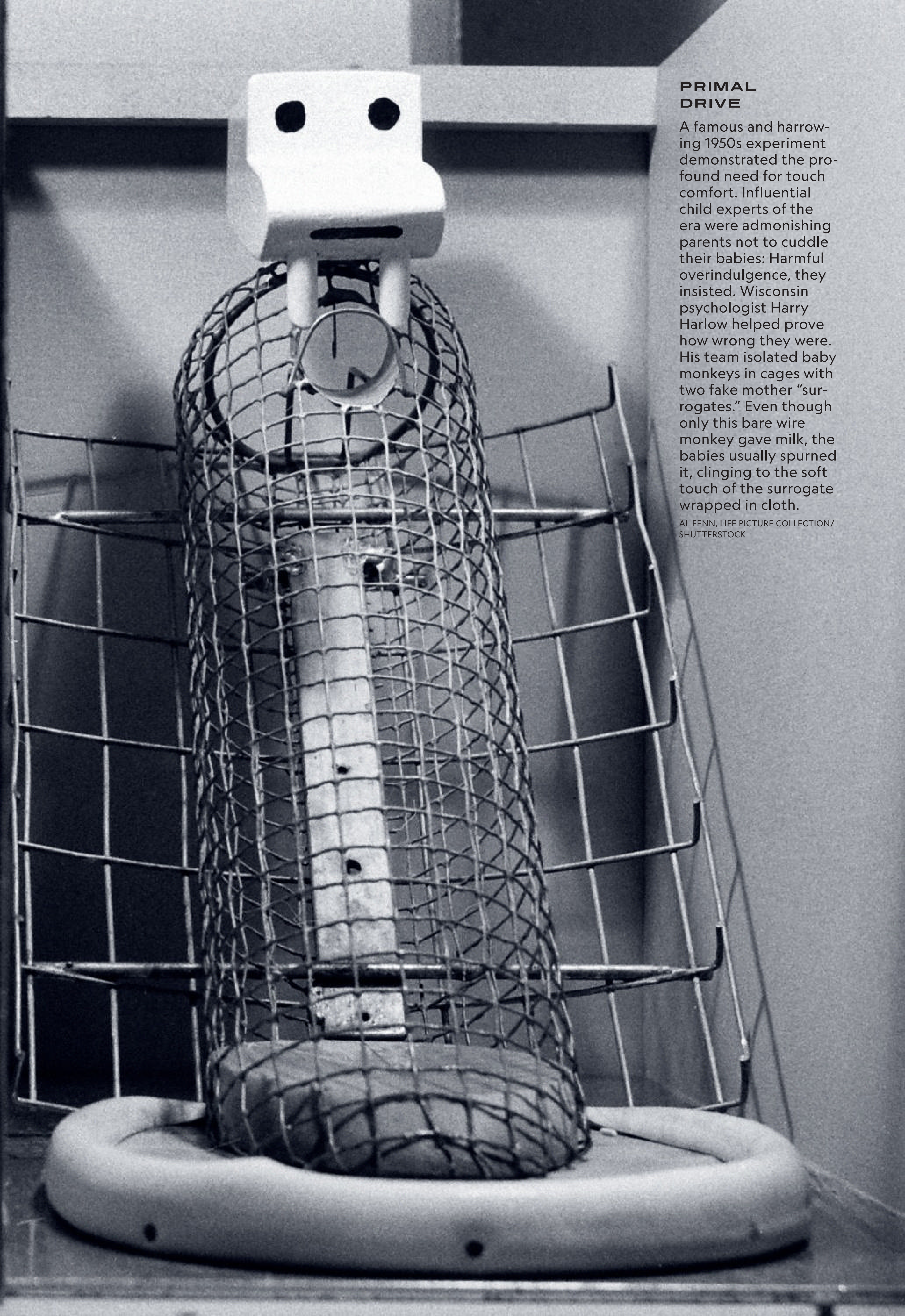


This translucent fabric acts as the skin of an experimental camera-computer combo that "feels" the touch of hands in a novel way—by converting their shadows into information. The Cornell University scientists who developed the mechanism, called Shadow Sense, are trying it out inside a soft, touch-reactive robot.



TOUCH

It was the first SENSATION we felt as infants—the soothing caress of others. Now researchers are learning more about how crucial HUGS and handshakes are to our HEALTH, and our HUMANITY.



PRIMAL DRIVE

A famous and harrowing 1950s experiment demonstrated the profound need for touch comfort. Influential child experts of the era were admonishing parents not to cuddle their babies: Harmful overindulgence, they insisted. Wisconsin psychologist Harry Harlow helped prove how wrong they were. His team isolated baby monkeys in cages with two fake mother "surrogates." Even though only this bare wire monkey gave milk, the babies usually spurned it, clinging to the soft touch of the surrogate wrapped in cloth.

AL FENN, LIFE PICTURE COLLECTION/SHUTTERSTOCK

A BODY'S SIGNALS

Arizona chiropractor John Ball treats world-class athletes—his grimacing patient on the massage table is American middle-distance runner Ben Blankenship—with powerful hands that manipulate while simultaneously picking up cues about muscle and bone. "I know how to use tissue and tactile feedback from the person's body," Ball says. "The more tactile sense, the more skin receptors you can stimulate, the more information you're bouncing back and forth between the local environment and the brain."

SNUGGLE UP
Inside New Delhi's Safdarjung Hospital, just born twins nestle against the skin of their aunt Neerja Kumari, while their mother, Sunita, recuperates. Kangaroo mother care—attending to newborns while they rest skin-to-skin against the mother or a surrogate—is well known, especially in developing countries, as a way to strengthen fragile low-birth-weight babies. A recent study coordinated by the World Health Organization at Safdarjung and four African hospitals found that kangaroo care is even more effective when it's nearly continuous and starts immediately after birth, rather than for a few hours a day after the baby is judged stable. Researchers estimate this approach could save 150,000 lives a year.

SAUMYA KHANDELWAL

ONE AFTERNOON in September 2018, six years after the work accident that destroyed his left forearm and hand in an industrial conveyor belt, a North Carolina man named Brandon Prestwood stood in front of his wife with an expression on his face that was so complicated, so suffused with nervous anticipation, that he looked torn between laughter and tears. In the little group gathered around the Prestwoods, someone held up a cell phone to record the curious tableau: the pretty woman with long hair and glasses, the bearded guy with a white elbow-to-fingertips prosthetic, and the wiring running from a tabletop electrical device up under the guy's shirt and into his shoulder.

Right through the skin, that is, so that Prestwood—his body, not his prosthetic—was, for the moment, literally plugged in. As part of an audacious set of experiments by an international network of neurologists, physicians, psychologists, and biomedical engineers, Prestwood had let surgeons at Cleveland's Case Western Reserve University slice into the end of his left arm and affix tiny electrical conductors to the truncated nerves and muscles. The surgeons then guided four dozen thread-thin wires up inside his half arm and out his shoulder. Afterward, whenever he peeled off the patch that covered them, Prestwood could see the wire leads poking out of his skin.

Welp, yep, they're wires, Prestwood would say to himself. *Coming out of my arm.*

He'd wasted too much time lost in depression after the accident. He felt purposeful now. And for some months he'd been making regular trips to Cleveland so that researchers could help him fasten on an experimental prosthetic arm, one of a new generation of artificial limbs with internal motors and sensor-equipped fingers. These devices are of great interest to rehab experts, but what the Case Western Reserve team most wanted to study was not simply the improved control the

PATCH WORK
Even the simplest touch to skin sets off neural messaging so complex that scientists are only beginning to mimic it through engineering. At the Johns Hopkins Applied Physics Laboratory, researchers are exploring an approach that uses what's known as e-dermis: pressure-reactive layered material. When attached to prosthetic hands, like the one holding this e-dermis patch, the material helps turn contact with another surface into a sensation the brain interprets as touch.
MARK THIESSEN

The National Geographic Society, committed to illuminating and protecting the wonder of our world, has funded Explorer Lynn Johnson's storytelling about the human condition since 2014.
ILLUSTRATION BY JOE MCKENDRY

new prostheses provide. What really fascinated the researchers—the focus of their exploration, each time they sat Prestwood down in the lab and plugged his wire leads into a computer—was the experience of human touch.

Because it's damnably, wondrously complicated, this critical interplay of skin, nerves, and brain: to understand, to measure, and to re-create in a way that feels… human. That's not a very scientific way to put it, but Brandon Prestwood is a case in point. Inside the Sensory Restoration Lab, as the Case Western Reserve researchers ran him through tests, there were encouraging developments; when Prestwood made the prosthetic hand close around a foam block, for example, he felt a pressure against the foam. A connection. A tingling that seemed to be coming from fingers he no longer possessed.

Amy Prestwood had never been able to join her husband, though, during his lab sessions in Cleveland. It was not until that September afternoon, when she went to the Maryland research symposium where Brandon was among the demonstrators of new technology, that the two of them could stand within reaching distance while Brandon was wearing the experimental prosthesis with his shoulder wires plugged in.

Brandon keeps on his phone that video recording of what happened next. He still loses his composure when he talks about it. No one has edited or polished this clip; all you see is two people facing each other in a big room, uncertain and awkward, like adolescents at a first dance. Brandon looks at his feet, looks at his prosthetic fingers, grins. With his right arm, the intact one, he points Amy toward his left: Come over here.

NEW SENSATIONS

When Brandon Prestwood's shoulder wires are connected to a computer stimulator, they carry signals to electrodes implanted in his upper arm. Combined with an experimental prosthesis, this can give Prestwood—whose lower arm was amputated after an accident—touch sensations that feel as though they're coming from that missing hand. At home in North Carolina, Prestwood uses alcohol swabs to clean around his wires. The tattoo honors one of the two infants he and his wife lost to amniotic fluid infections. His plea, as a research volunteer: Don't damage the tattoo.

●

THE GROWING LITERATURE about our sense of touch is rich with new science, conjecture, and fantastical propositions for the future—but there are four seconds in that video I want to describe, just as Amy wraps her fingers around the hand of Brandon's prosthetic. His head snaps up. His eyes widen. His mouth falls open. She's watching him, but Brandon is staring straight out, plainly not seeing anything. "I could *feel,*" he told me. "I was getting feedback. I was touching her. I was crying. I think she was crying."

She was. The day he showed me the video we were deep into the pandemic and sitting outdoors; Prestwood had been in the Cleveland lab for hours and wanted a cigarette. We'd met in person for the first time that morning. I can't remember how we resolved the hesitant do-we-shake-hands-or-not moment—hesitant not because Prestwood has only one hand, but because it seemed as though everybody on Earth was still trying to figure out how to approach each other, how fully to close the distance, how to touch.

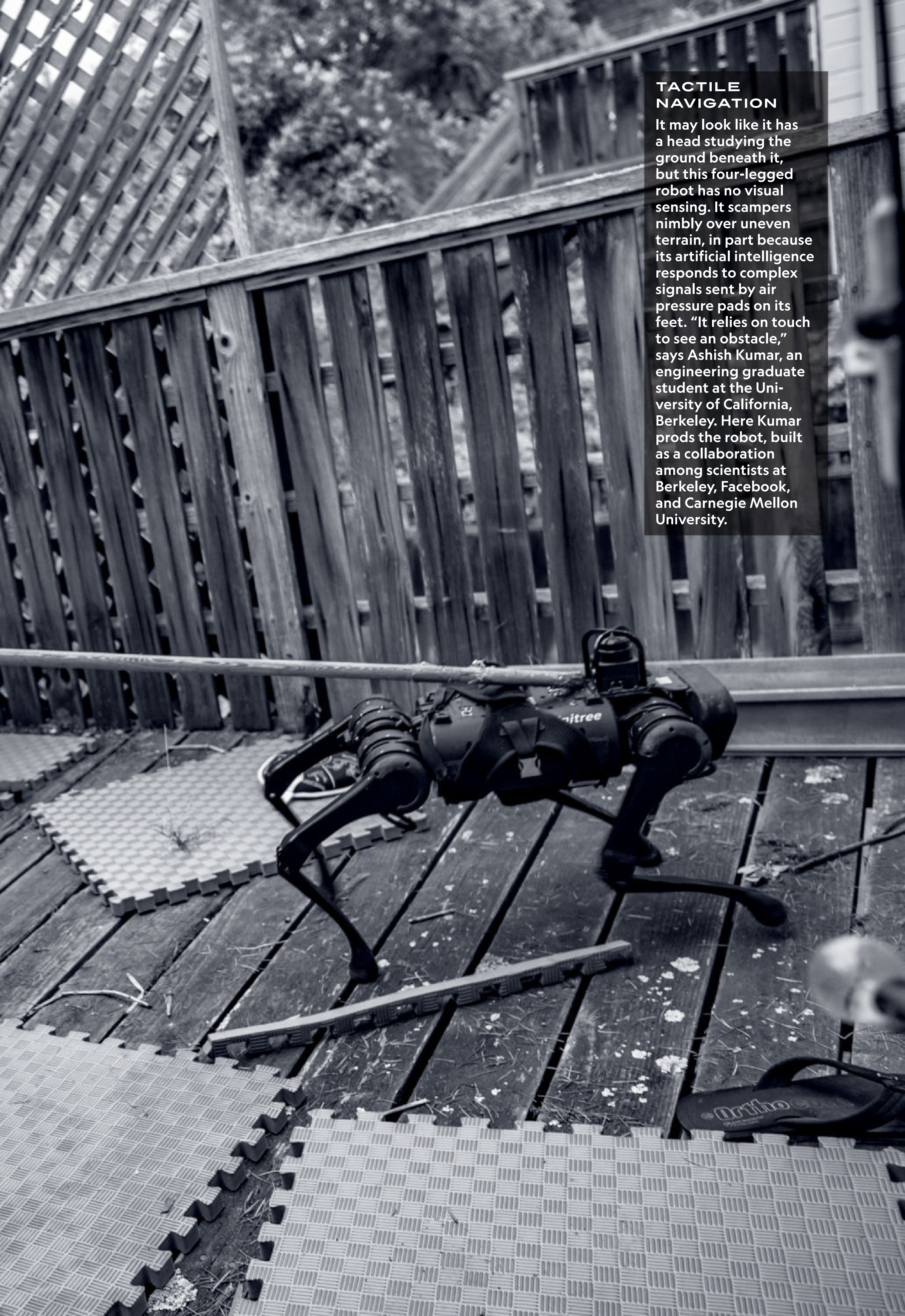
Maybe you recall the photos of people pandemic-embracing through shower curtains or hanging plastic. This magazine published

an especially affecting one, a clear drop cloth clipped to a clothesline; with the plastic between them, a woman and her daughter clung to each other for the first time in months. I swear I know the sound and feel of that moment: My own daughter improvised something similar, after the weird aching season of across-the-backyard distanced visits, and I can still bring to mind the mercy of that hug.

Through a barrier, yes. Crinkly, slippery. Plasticky. A diminishment, you'd think. But my "need state," as Liverpool John Moores University neuroscientist Francis McGlone puts it, was too heightened for me to notice. "It's like being low on a vitamin," McGlone told me. "You needed to be topped up again."

Topped up with what, exactly? My grandmother would have looked at me sideways for imagining that was a question that merited answering. But neurologists and psychologists have biological markers now to explain what seems intuitively obvious to so many of us—that most human beings require the physical presence of others, the comforting touch of others, in order to stay healthy. Take in this academic-sounding prose, before I tell you where it first appeared:

Touch is a fundamental aspect of social interaction, which is a fundamental human need… Social



TACTILE NAVIGATION

It may look like it has a head studying the ground beneath it, but this four-legged robot has no visual sensing. It scampers nimbly over uneven terrain, in part because its artificial intelligence responds to complex signals sent by air pressure pads on its feet. “It relies on touch to see an obstacle,” says Ashish Kumar, an engineering graduate student at the University of California, Berkeley. Here Kumar prods the robot, built as a collaboration among scientists at Berkeley, Facebook, and Carnegie Mellon University.

touch calms the recipient of the touch during stressful experiences… can reduce activation in threat-related regions of the brain… can influence activation in the stress pathway in the nervous system, reducing levels of the stress hormones… has been found to stimulate the release of oxytocin, a neuropeptide produced in the hypothalamus… Elevated levels of oxytocin are associated with increased trust, cooperative behavior, sharing with strangers, the more effective reading of others' emotions, and more constructive conflict resolution.

That's from a federal lawsuit against solitary confinement. Lawyers bringing the decade-old suit, on behalf of inmates at a California maximum-security prison, argued that its practice of isolating inmates for years—with an elaborate security system that nearly eliminated physical contact with others, even guards—amounted to unconstitutional cruel and unusual punishment. Details of a settlement are still being fought over in court, but part of the permanent record now is the expert report written by University of California, Berkeley psychology professor Dacher Keltner, who for more than 15 years has been teaching and supervising research in the science of touch. "It's our earliest and, you could argue, our fundamental language of social connection," Keltner told me.

Earliest evolutionarily, he means: We humans are believed to have used "tactile communication," as the scientific papers say, before we began figuring out speech. And earliest individually: Touch is now understood to be the first sensation a fetus perceives. At birth and during the initial months of life, it's an infant's most critical and fully developed sense—the way babies start exploring the world, developing confidence, learning where their bodies end and everything else begins.

One of psychology's most influential and disturbing studies of touch featured babies, in fact, although in this case they were lab monkeys. In the late 1950s, a team led by University of Wisconsin psychologist Harry Harlow took newborn rhesus macaques from their mothers and isolated them in cages with two vaguely monkey-shaped surrogates, one made of bare wire and the other covered with soft terry cloth. In one of Harlow's experiments, only the wire surrogate dispensed milk. The babies taught themselves to drink from it, but as soon as they

'IF IT WILL HELP SOMEONE ELSE'

After a malignancy in 2018 forced retired Michigan teacher Neil Oldham to have his right lower arm and hand amputated, he agreed to join the University of Michigan's touch-restoration research—which meant new surgery to implant electrodes. "I was blessed having both arms and legs for 70 years," Oldham says. "I'm OK with being a guinea pig if it will help someone else."

TOP

THE EXPERIMENT

The hook prosthesis Oldham wears for daily life is fine, he says; he enjoys puttering in his basement woodworking shop. But the limb injuries of post-9/11 war veterans were on his mind when he volunteered for experimental surgery that might let him sense touch in his missing hand.

BOTTOM

PREP FOR SURGERY

Plastic surgery resident Carrie Kubiak checks on Oldham at U-M Health's University Hospital, prior to surgery to implant electrode wires. Lead surgeon Paul Cederna has marked the skin that will be cut. When describing these experiments, Cederna has called the process "melding humans and machines."

MICHIGAN

BECOMING BIONIC

Deep into a six-hour operation, Kubiak (center) works with plastic surgeon Theodore Kung to pinpoint the spots for implanting electrode wires in Oldham's arm. Each group experimenting with touch restoration uses a different technique; the University of Michigan team begins by wrapping nerve endings with small pieces of muscle. (This also reduces amputees' phantom limb pain, Cederna has found.) The nerve endings grow into the muscle, and wires are implanted into the wrapped bundles, so stimulation will fire muscle and nerves.

TOP

THE CONNECTORS

The operation concluded, 12 leads—each containing two wires—now poke through the skin of Oldham's upper arm. The researchers hope that stimulation to Oldham's nerves and muscles eventually will work with sensors in a prosthesis to send signals his brain perceives as emanating from the missing hand. "Regeneration of actual limbs—that would be the most ideal," Oldham said a few days earlier. "I'm a dreamer."

BOTTOM

MIND CONTROL

After Oldham's recovery summer, researchers bring him into a University of Michigan lab for early tests. The prosthesis he's wearing has no active sensors to respond to touch; that phase will come soon. But because surgeons implanted his electrodes into bundles of muscle-wrapped nerve endings, Oldham finds he has remarkable brain-to-muscle control over that bionic hand. "It did what I wanted it to do," he says. "I was impressed."

were done feeding—and whenever the scientists thrust a horrible head-waggling mechanical monster at them—they scurried to their softer fake mothers, grasping the cloth midsections in a clutch that can best be described as a desperate-looking embrace.

There's an old Harlow monkey video floating around online, and it's awful to watch: Harlow in his lab coat, calmly narrating to an onlooker as a lone caged baby scooches up against the terry cloth. But the psychologist had what was then a heretical point to make. Influential Western child-rearing authorities of his era were instructing parents not to touch their babies any more than absolutely necessary—to regard cuddling and kissing infants and small children as antiquated forms of overindulgence. (Your children will grow up weak and dependent, they insisted; besides, it's unsanitary.)

Harlow's monkey experiments were ethically repugnant by modern sensibilities, but they're part of the reason we now know how wrong those authorities were. The baby macaques, our close evolutionary cousins, needed what Harlow called "contact comfort" so profoundly that they spurned a steady food source in favor of a soft touch.

Post-Harlow studies have multiplied the evidence for the power and chemistry of contact comfort. Scientists working with lab rats, for example, have found that gently handling and stroking the rats benefits the animals' ability to learn and to manage stress. The right kind of skin-to-skin touch produces specific, measurable improvements in human babies' health too: heartbeat, weight, resistance to infection. Neonatal incubators were designed to hold preemies and other low-birth-weight babies in protective sterile isolation, but some hospitals now also treat these babies with a vividly named protocol called kangaroo mother care—placing the newborns against their mothers' bare chests, as soon as possible after birth, and keeping them there for many hours at a time.

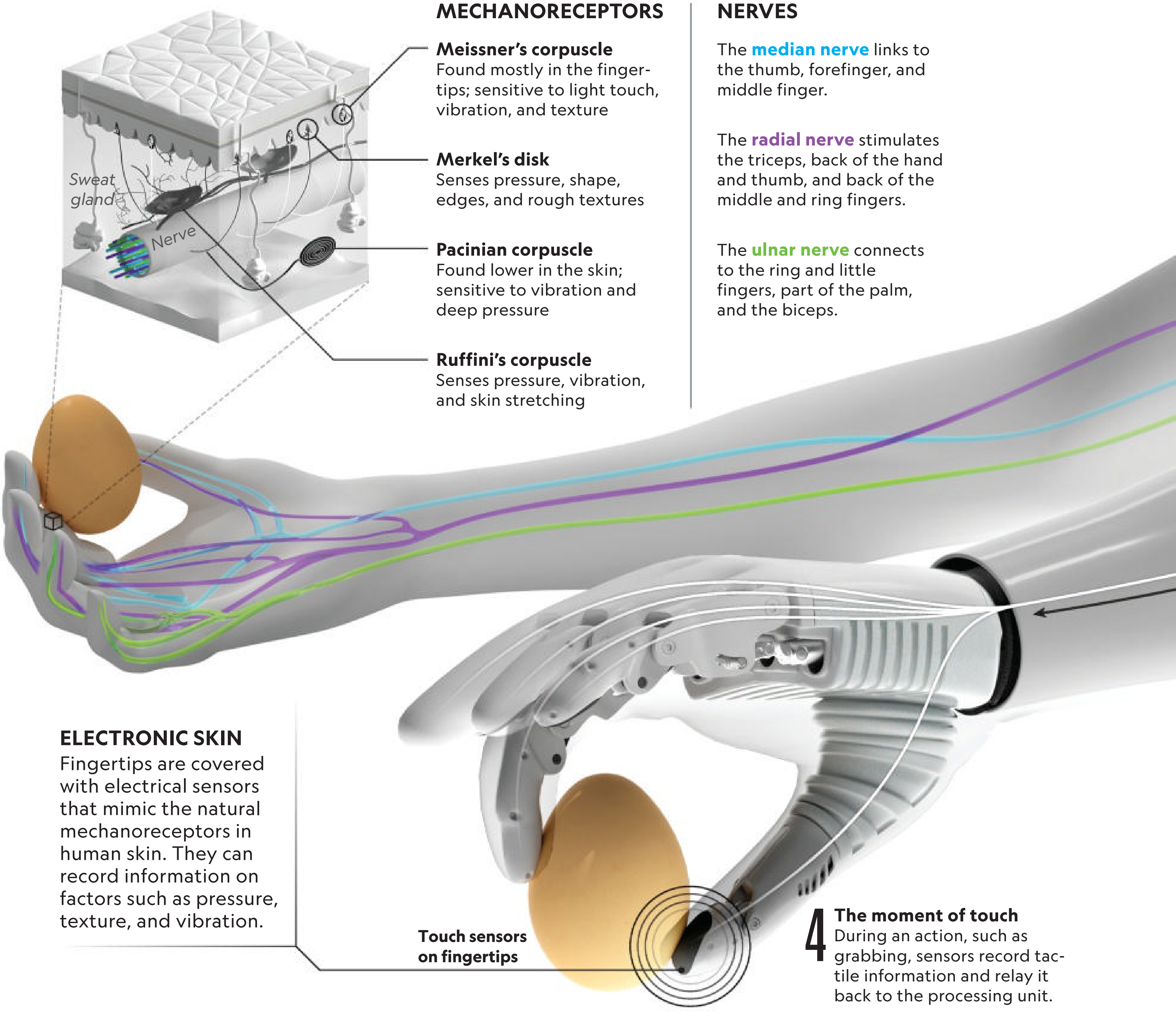
Babies held skin-to-skin against their mothers have constant, immediate access to breast milk and can absorb protective maternal microorganisms. Hospital studies have also found that when the mother is ill or otherwise unable to hold the baby for long periods, another adult can substitute as a temporary skin-on-skin kangaroo. It's not romantic hyperbole to say that

RESTORING TOUCH

Today’s most advanced experimental prosthetics are designed not only to move with precision but also to feel. This robotic arm, created by researchers at Sweden’s Chalmers University of Technology, is surgically attached to bone and interacts with nerves in the arm to relay touch to the brain.

THE BODY’S NATURAL SYSTEM

Muscles receive signals from the brain to interact with the physical world. In response, sensors in human skin called mechanoreceptors, which detect touch, pressure, vibration, and stretching of the skin, send information back to the brain via the main nerves of the arm.



MECHANORECEPTORS

Meissner’s corpuscle
Found mostly in the fingertips; sensitive to light touch, vibration, and texture

Merkel’s disk
Senses pressure, shape, edges, and rough textures

Pacinian corpuscle
Found lower in the skin; sensitive to vibration and deep pressure

Ruffini’s corpuscle
Senses pressure, vibration, and skin stretching

NERVES

The **median nerve** links to the thumb, forefinger, and middle finger.

The **radial nerve** stimulates the triceps, back of the hand and thumb, and back of the middle and ring fingers.

The **ulnar nerve** connects to the ring and little fingers, part of the palm, and the biceps.

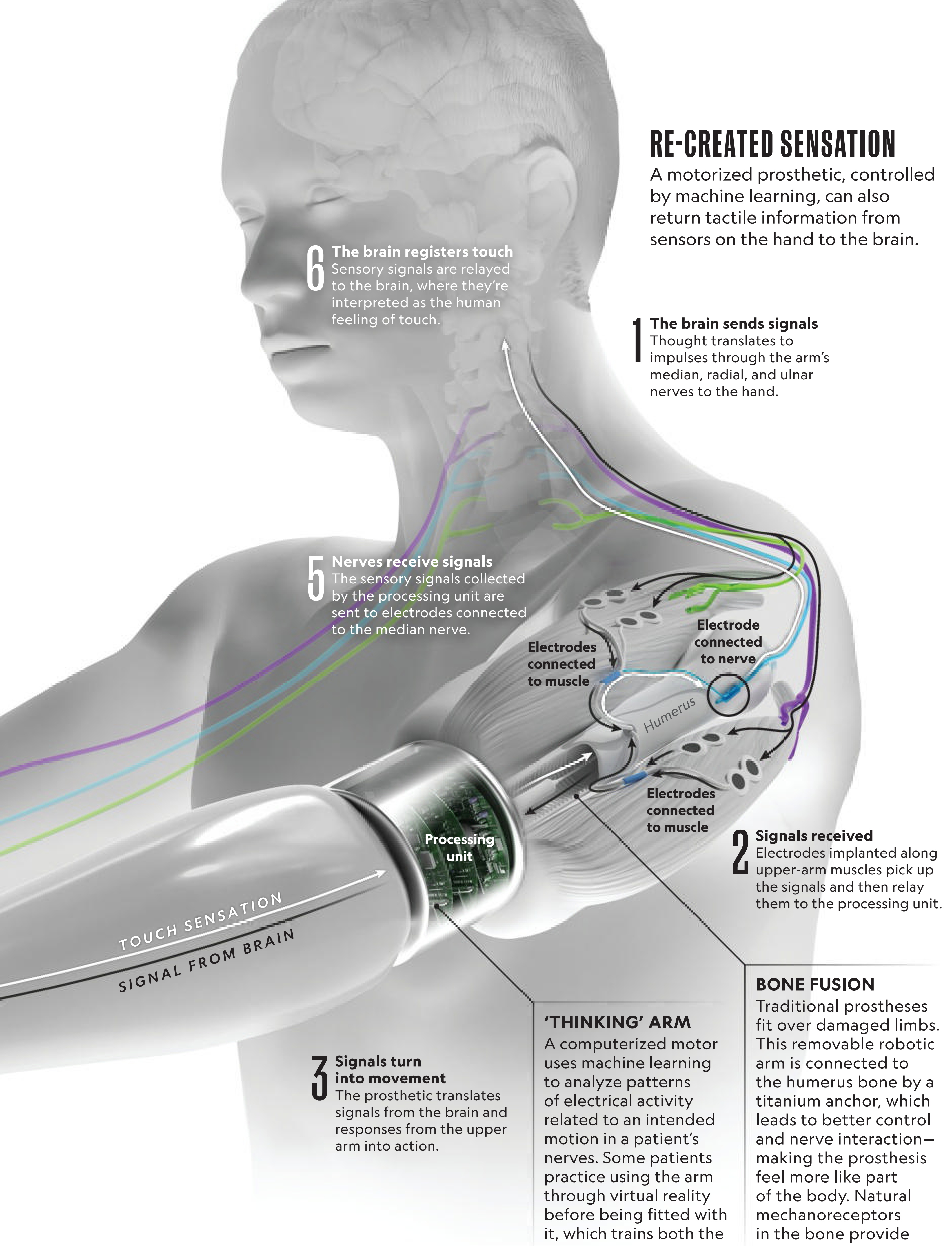
ELECTRONIC SKIN

Fingertips are covered with electrical sensors that mimic the natural mechanoreceptors in human skin. They can record information on factors such as pressure, texture, and vibration.

4 **The moment of touch**
During an action, such as grabbing, sensors record tactile information and relay it back to the processing unit.

RE-CREATED SENSATION

A motorized prosthetic, controlled by machine learning, can also return tactile information from sensors on the hand to the brain.


Electrodes connected to muscle
Electrode connected to nerve
Humerus
Electrodes connected to muscle
Processing unit
TOUCH SENSATION
SIGNAL FROM BRAIN

1 **The brain sends signals**
Thought translates to impulses through the arm's median, radial, and ulnar nerves to the hand.

2 **Signals received**
Electrodes implanted along upper-arm muscles pick up the signals and then relay them to the processing unit.

3 **Signals turn into movement**
The prosthetic translates signals from the brain and responses from the upper arm into action.

5 **Nerves receive signals**
The sensory signals collected by the processing unit are sent to electrodes connected to the median nerve.

6 **The brain registers touch**
Sensory signals are relayed to the brain, where they're interpreted as the human feeling of touch.

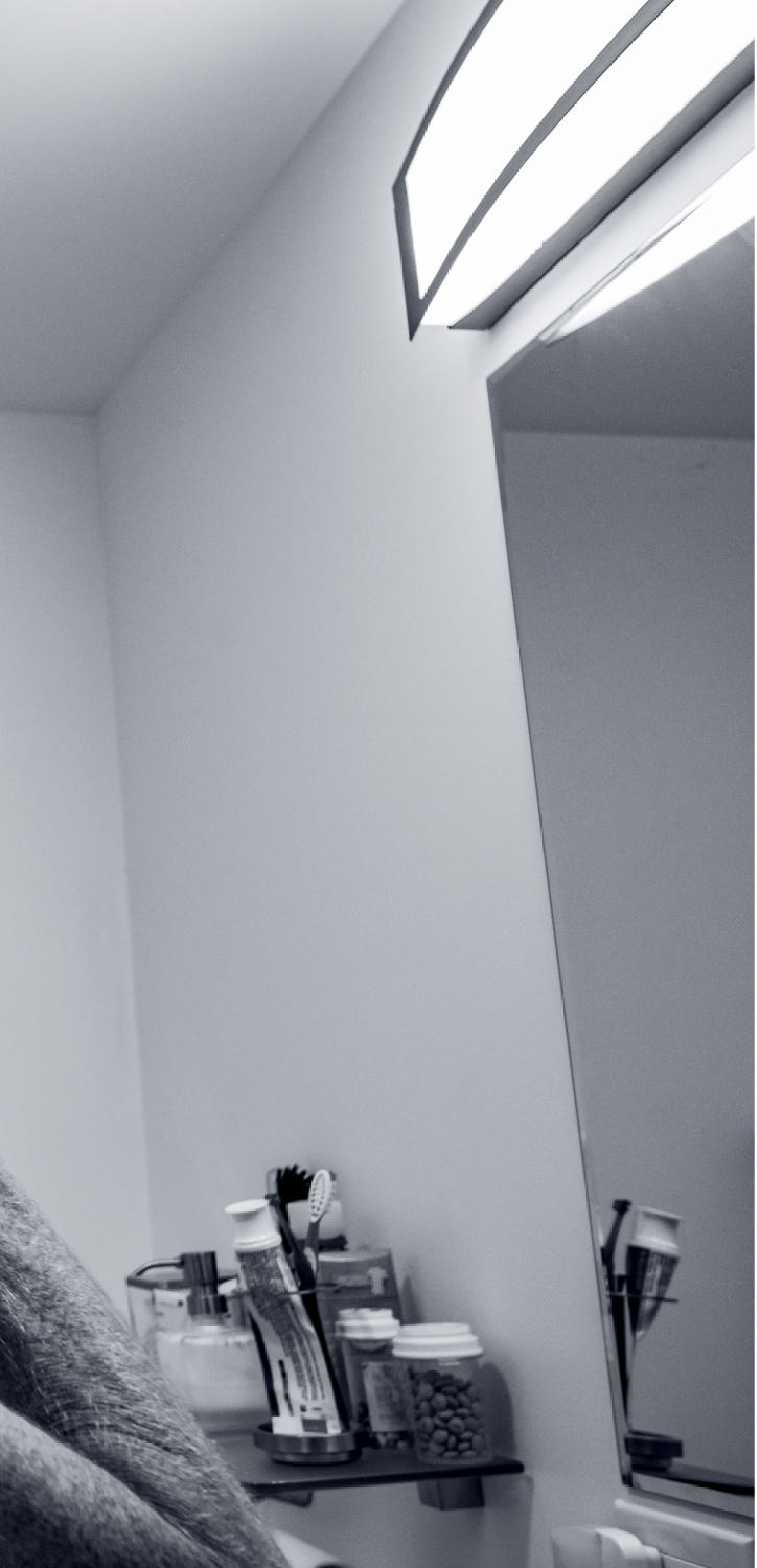
'THINKING' ARM

A computerized motor uses machine learning to analyze patterns of electrical activity related to an intended motion in a patient's nerves. Some patients practice using the arm through virtual reality before being fitted with it, which trains both the person and the unit.

BONE FUSION

Traditional prostheses fit over damaged limbs. This removable robotic arm is connected to the humerus bone by a titanium anchor, which leads to better control and nerve interaction—making the prosthesis feel more like part of the body. Natural mechanoreceptors in the bone provide additional sensations.

JASON TREAT, NGM STAFF. ILLUSTRATION: SINELAB. SOURCES:
MAX ORTIZ CATALÁN, CHALMERS UNIVERSITY OF TECHNOLOGY;
DALE PURVES AND OTHERS, EDS., *NEUROSCIENCE*, 2ND ED., 2001



FEELING BETTER

After a 1985 car crash broke his neck, landscaper Scott Imbrie spent years with damaged and scrambled tactile perception: Hot felt like cold, for example. As part of University of Chicago touch research led by neuroscientist Sliman Bensmaia, Imbrie now has brain implants that can link to a computer through pedestals on his head. Here at home in Illinois, Imbrie preps for one of his frequent sessions in a lab. “This sounds crazy,” he says, “but I’m learning how to feel again.”

the physical warmth and touch of a mother—or a father or any other attentive person who understands the delicacy required—can keep a newborn baby alive.

●

FEEL THESE,” Veronica Santos said, and pulled four rectangular tiles from a desk drawer. “With your eyes closed.”

What my fingers told me, within seconds: Plastic, all four tiles. Pits on one. A bump on another. Curves. Angles. A raised square about the size of a stamp.

If you have the use of at least one hand, you engage in this kind of instant skin-to-brain memo over and over every day. Which of the shapes inside your purse is the pen you’re groping for? Is your wallet still in your back pocket? Did the kids leave the car upholstery sticky again? Right now, assuming you’re wearing a garment, try feeling the cloth: pants, shirt, pajamas, doesn’t matter. Just don’t look down.

Santos, an engineer who directs the Biomechatronics Laboratory at UCLA, had me do that too—describe the texture of the skirt I was wearing, without looking at it. You and I likely reacted the same way: We didn’t plunk down a finger, the way we might point out a spot on a map. Instead we moved a fingertip or two lightly back and forth across the fabric, or rubbed it between forefinger and thumb.

Anatomy taught us this, not culture; we humans are wrapped, as I once heard another scientist say, in “an incredibly complex sheet covered with sensors.” The skin, that is, our largest organ. Its layers contain hundreds of thousands of receptor cells, unevenly distributed around the body’s surface, specialized for various jobs. Some shoot the brain signals about temperature or the harmful disruption we perceive as pain. Some seem specialized to soothe; neuroscientist Francis McGlone is part of an international group of scientists studying receptors, densest in the hairy skin of the arms and back, that produce a pleasant feeling when the skin that contains them is brushed or stroked.

And some receptors send the brain the kind of informational detail that helps tell us, all day long, what we’re touching and doing and using. Mechanoreceptors, these are called; conveniently, evolutionarily, their density is especially high along the palmside skin of the fingertips and hand. They’re working for you—again, if you have the use of at least one hand—at this very moment. You’ve been turning the magazine pages with your fingers, right? Try folding over one page. Then with your eyes closed, run a finger down that fold, against the smoothness of the page behind it. Let your fingers find the page corners, the covers, the spine.

Done? OK. Just now, from your hand to your brain, so much was happening. The pressure against your fingertip pads, the distortion to your skin, the vibrations you didn’t notice as you slid your finger over surfaces—each of these tiny alterations to your own sensor-covered sheet was stimulating its mechanoreceptors. Four varieties of such touch receptors have been identified, each with a subspecialty of its own; your vibration-sensing mechanoreceptors, for example, were firing away as your fingertips moved across textures of paper and cloth. Nerves carry those signals from the skin up to the brain, which instantly sorts and understands: Smooth! Different kind of smooth! Denim! Corduroy!

None of this takes place in isolation, of course. Context—smells, sounds, memory, situational input—affects everything. *I know that’s corduroy because I learned long ago what corduroy feels like.* It’s why the touch of another’s hand can please in one context and repel in another. “The entirety of our perception is built against the lifetime of our experience,” said Case Western Reserve University biomedical engineer Dustin Tyler. “The system we’re working with”—the interplay of receptors, nerves, and brain, he means—“is always taking information in, filing it, associating it, connecting it, and creating our us. There is no beginning and end to it. We’re trying to tap into that.”

Tyler leads the multispecialty team working with Brandon Prestwood and eight other patients, all of whom—because of amputation or in one case paralysis—have lost at least one limb’s natural capacity to feel touch. A conversation with Tyler can ricochet between metaphysics and plainspoken exuberance; I once asked him how he’d found his way from a college engineering major to sensory restoration experiments, and his thoughtful reply included “Holy crap!” and “Awesome.” Electrical engineering, awesome. Neural networks, same. Neural networks run on the body's internal electricity, after all; it's electrical pulses that carry signals up and down the nerves. "I was fascinated by the brain," Tyler told me. "I'm still amazed every day at how the machine we ride around in works."

The overlap of neuroscience and engineering has a long history. During the 1960s and '70s, for example, scientists began successfully using electrical stimulation and electrodes, surgically implanted or attached to the skin, to activate the muscles of people with paralysis. Tyler's wife, Joyce, is a retired occupational therapist, and her work with post-amputation patients helped draw his attention to a parallel 21st-century neuroengineering challenge: What about touch? With so many post-9/11 Iraq and Afghanistan war veterans suffering explosives injuries, the U.S. Veterans Affairs and Defense Departments were heavily funding prosthetics research. In their quest for "near natural," a term the researchers sometimes use as they incorporate new technology into new kinds of replacement limbs, could they make these limbs feel near natural as well? Might a prosthesis with built-in sensors, in conjunction with implanted electrodes, let an amputee perceive touch through the device, as though it were a living body part?

●

We humans are WRAPPED,
as I once heard a scientist say,

in 'an incredibly complex sheet
covered with SENSORS'—our SKIN.

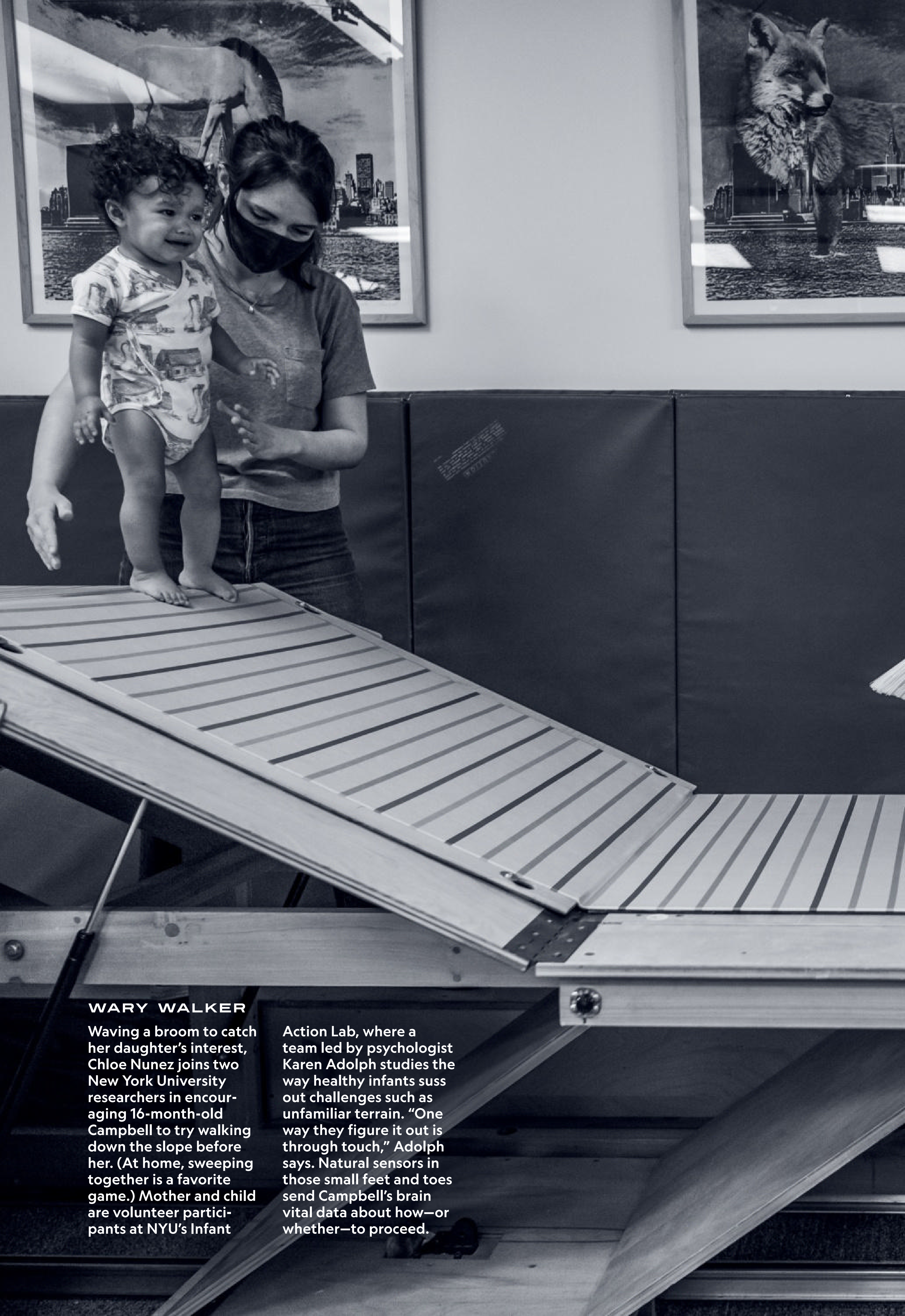
The answer, based on investigations at Case Western Reserve and a half dozen other research centers, is yes. Sort of. "We've found this is a challenge with all our subjects—what words do you use?" Tyler said. " 'Tingle' is the most typical. A lot of the time they have no reference frame. It's not like anything they've felt before."

Like a cold drop of water, one patient told him. Or that prickly sensation after your hand or foot has fallen asleep and is just starting to come back. "I use the word 'buzzing' sometimes, but that's almost too strong," Prestwood told me. "Like somebody's taking the tip of a sewing needle, and not trying to prick my skin—just touching it."

Each center is experimenting with its own combination of implants and prostheses; the graphic on pages 54-55, created with the guidance of engineer Max Ortiz Catalán at Sweden's Chalmers University of Technology, shows the arrangement Chalmers scientists have developed. Here's the central idea: A post-amputation patient—a man like Prestwood, say, who's lost his whole forearm—has truncated nerves within the part that remains. Those nerves are still able to send signals the brain perceives as coming from the missing limb; this can be one of the causes of phantom limb sensation.

So the trick is restoring the signaling. The sensors being built into these experimental prostheses can convert contact with a surface—a prosthetic finger touching a tabletop, for example—into electric signals. This sends data to a computer, which determines the nerves that will have to be stimulated to make the brain perceive the touch in the appropriate place. (Index finger? Thumb? Second knuckle on ring finger?) The computer sends pulses down the patient's implanted wiring to an electrode, which stimulates the indicated nerve, sending biological electric pulses up the nerves. *Voilà:* sensory information, ideally the right information, en route to the brain.

When it's working correctly, all this should happen nearly instantaneously, from the brain's perspective, like the neural signaling we're born with. But no two bodies are exactly alike, and for the participants who volunteer, so far about two dozen in U.S. and European research hospitals, the process demands forbearance: serious surgery followed by many hours in research labs,



WARY WALKER

Waving a broom to catch her daughter's interest, Chloe Nunez joins two New York University researchers in encouraging 16-month-old Campbell to try walking down the slope before her. (At home, sweeping together is a favorite game.) Mother and child are volunteer participants at NYU's Infant Action Lab, where a team led by psychologist Karen Adolph studies the way healthy infants suss out challenges such as unfamiliar terrain. "One way they figure it out is through touch," Adolph says. Natural sensors in those small feet and toes send Campbell's brain vital data about how—or whether—to proceed.

GENTLE STROKES

Nerve fibers called CT afferents, clustered in the arms and back, can make people feel pleasant—and warmly connected to others—when those areas are brushed or stroked. University of Virginia neuroscientists Meghan Puglia and Kevin Pelphrey, exploring possible links between unusual CT response and autism or other developmental differences, are recording the brain activity of typically developing babies such as nine-month-old Ian Boardman, here being brushed by Puglia.

answering questions while tethered to a computer. "Where do you seem to be feeling that?" "How about now?" Even so, Prestwood and other participants told me, they signed on mostly for the chance to help scientists learn how this will play out—whether injured veterans and other amputees may someday be able to wear a near-natural limb that actually feels that way.

"I just wanted to see if I could pay it forward," said Keven Walgamott, a Utah real estate agent who lost parts of his right arm and foot two decades ago after a power line sparked while he was lifting a pump out of a well outside his home. Starting in 2016, Walgamott spent more than a year as a research volunteer at the University of Utah, where he was temporarily implanted with electrodes, including some developed by scientists there. Inside their lab, wired into a computer, Walgamott would put on one of the new sensorized prostheses—this one named the LUKE, for Life Under Kinetic Evolution but also for Luke Skywalker, the *Star Wars* Jedi who loses his hand in a light-saber fight with Darth Vader. By the end of *The Empire Strikes Back,* Luke has a prosthetic that can apparently do everything, including feel. If you enter "Walgamott eggs" or "Walgamott grapes" into a search engine, you'll see him in a Utah lab with the LUKE: Concentrating, his face sober, he's performing the kind of simple tasks that are almost impossible for hands that can't feel.

He lifts a raw egg in its shell, with just the right delicacy, and sets it gently into a bowl. He holds a grape cluster with his actual hand, closes a prosthetic thumb and finger around a single grape, and pulls it off without squashing it. Video clips from other research centers show similar small triumphs: at Case Western Reserve, a blindfolded patient using sensorized prosthetic fingers to pinch and pull off the stems of cherries; in Sweden, a Chalmers patient inside his own garage, using tools with both his natural hand and his prosthetic one.

But what many of the study volunteers most wanted to feel—what they longed for, they told Tyler and other scientists—was the touch of human skin. "I was amazed at how many of them just wanted to connect with somebody," Tyler said. "It wasn't functional. It was just: 'I want to hold my wife's hand.' "

Once I asked Prestwood, after apologizing for the boorish question, why it mattered so much to perceive Amy's fingers around his missing left hand when his intact right hand had been there all along. He didn't take offense. He said it was hard to put into words. Finally he said: It made him feel whole. "Because it's something I lost," he said. "For six years I had not held my wife's hand with my left hand, and now I was. It's the emotion that goes with any kind of touch. It is … it's being complete."

Tyler found this at once moving, profound, and provocative. What does it mean to feel the joy of a loved one's touch when the sensation is like the tip of a sewing needle? And if the right circumstances can make a certain kind of zap to the cortex register as the squeeze of human fingers, what might that imply for individuals separated by distance? "Like, holy cow. What could we do?" Tyler said. "This is way beyond prosthetics."

●

W**HICH BRINGS US** to Veronica Santos, and her Los Angeles lab full of robots. "Biomechatronics" essentially means what it sounds like, the blending of biological and mechanical science, and Santos specializes in developing sensors for robot hands. Much of her work is meant to make robots more useful in medical settings and in places that are dangerous for humans, like the depths of the sea. But three years ago she began collaborating with Tyler on a series of experiments in … well, the nomenclature is still unsettled. "Remote touch." "Distributed touch." Just picture this: One person in Los Angeles, one person in Cleveland. Across 2,000 miles—the distance from UCLA to Case Western Reserve—they're trying to shake hands.

A robot is involved, and I'm about to explain how; Santos and Tyler decided to hook me up for a go as the Cleveland end in one of their experiments. Scientists and science fiction writers have for many decades considered how this might play out, a person in one place making what feels like physical contact with a person or an object somewhere else. If you've ever felt a cell phone vibrate, you're part of the endeavor: That's a wireless signal, from another locale, firing a minuscule motor that fires mechanoreceptors in your skin.

The engineering term of art is "haptics," from the Greek *haptikos:* relating to the sense of touch. Any technology designed to set off touch sensations is haptic—those restaurant pagers that buzz in your hand when your order's ready, for example. You can buy virtual reality gloves now, to be worn with virtual reality goggles and wired to make your actual fingers and palms feel something like contact as your virtual hands touch virtual things. (You see a wall in the virtual room your goggles are displaying; lifting your actual hand puts your virtual hand against the wall, and a force in the gloves pushes back to create the illusion that you can't bust through. Or your virtual fingers touch a virtual tractor on virtual farmland, and your actual fingers feel the engine throb.) Gamers are currently the biggest consumer market for such gloves; they're also being used to make VR training devices, such as flight simulators, feel more realistic.

Compared to the symphony that is natural human touch, though, the technology has a long way to go. That's not my metaphor, the symphony; I heard it from three different scientists trying to help me appreciate the orchestral coordination behind sensations we take for granted. "I'm making do with these amazing engineered materials, and they're still our kludgy way of trying to re-create what my little nephew was just born with, nine months ago," Santos told me. "I'm still humbled by that."

The day I set out to feel her fingers from eight states away, Santos was wearing a T-shirt, blue jeans, and a pandemic face mask. I caught a wobbly glimpse of her, livestreamed and in 3D, through the VR goggles two Case Western Reserve researchers had strapped onto my head. Then she tipped abruptly sideways, vanishing from view, and what was I seeing now? Floor tiles. A desk leg, two shod feet—Oh. Santos's feet. I raised my goggled eyes. "Hi," Santos said.

What she was greeting was a wheeled robot, which after bumbling around the UCLA lab furniture had finally stopped to point its video camera face at hers. To use the researchers' parlance, I was "embodying" that robot, seeing through its eyes, hearing through its microphone, and lurching like a drunk because of the human incompetently navigating from Cleveland. Nothing so remarkable about that, in the era of drones; the novel part was my own right hand, which was—here's that word again—embodying the metal and plastic hand of the rolling Los Angeles robot. Taped to my gloved palm and my index finger were two metal disks. Wires connected the disks to a lab computer, which was internet connected to the robot, which had tactile sensors on its own robot fingers. Whenever the robot touched a surface, the sensors shot pulses to its robot brain—its computer. Those pulses zipped across the country, down the lab wiring onto my hand disks, through my skin, and then up my nerves into my somatosensory cortex.

Buzzing, Prestwood had said, but fainter. A needle's tip. Those were good words for this—plus a pressure against my fingers when I, meaning the robot, closed my hand around the plastic wineglass on a table beside Santos. The experiment was designed to suggest two separated people celebrating a business deal with a glasses-clinking toast and a handshake. I failed the toasting part; my robot self kept dropping the glass. But the researcher whose place I had temporarily taken, a Case Western Reserve graduate student named Luis Mesias, was much more adept by now with long-distance touch. He'd learned how to maneuver his gloved hand expertly enough to pick up the glass in Los Angeles by the stem and tap it against a second

What many of the study volunteers most wanted to FEEL with their prostheses—what they longed for—was the TOUCH of HUMAN SKIN.

COW COMFORT

Aimee's Farm Animal Sanctuary, in Arizona, opened as a respite center for animals. Then families with children on the autism spectrum spread the word: Touching the gentle animals calmed their kids. Now, says Aimee Takaha, here with a Holstein named Sam, all kinds of clients reserve hour-long animal-cuddling sessions.

TOUCH THERAPY

Margaret Malarney was a 14-year-old athlete and live wire before undergoing lymphoma treatment in 2020. She suffered internal bleeding that seemed at first to have devastated her brain. Her parents, John and Kate Malarney, braced for bereavement—until, as Kate lay holding her, Margaret spoke her own name. Now Margaret progresses in special classes, with a barrage of loving rehab that includes abundant touch. "It gave us an entry to her," says Kate, joining hands with Margaret at home in Chagrin Falls, Ohio. The teen arches her spine while movement educator Polly Manke supports her shoulders. "It was the first way we were reaching her."

glass his counterpart had raised. Feeling the tap, in Cleveland. *Clack.*

Mesias, embodying the Santos lab robot, has long-distance peeled a banana. He has long-distance squeezed a toothpaste tube with the gentle precision of a person preparing to brush his teeth. Give the research enough time and you can conjure a future in which touch is transmitted, as vividly as sight and sound are now, into tele-everything: work, travel, shopping, family gatherings. Consolation. Sexual intimacy. Medical care, the kind that requires a practitioner's touch. Maybe in the metaverse, that not-yet-realized virtual gathering place that has leaped from sci-fi imagining into corporate business models, something we put on our actual bodies—gloves, a suit, whatever—will convince our brains that we truly are feeling virtual people, virtual animals, virtual things.

Maybe. If I hadn't been looking right at Santos's face as she went in for the handshake ... if I hadn't once shaken her actual hand and walked beside her in Los Angeles learning the timbre of her voice ... in another context, I mean, the sudden buzzing-and-needles jolt to my skin would have felt nothing like the clasp of human fingers. It made me suck in my breath, though. I *could* see her face, as she laid her bare hand over the robot's, and for a long time afterward I thought about Brandon and Amy Prestwood,

and the solidity of my daughter's embracing arms beneath that barrier of plastic, and how fully the mind can meld story and setting with the pulses running along human nerves.

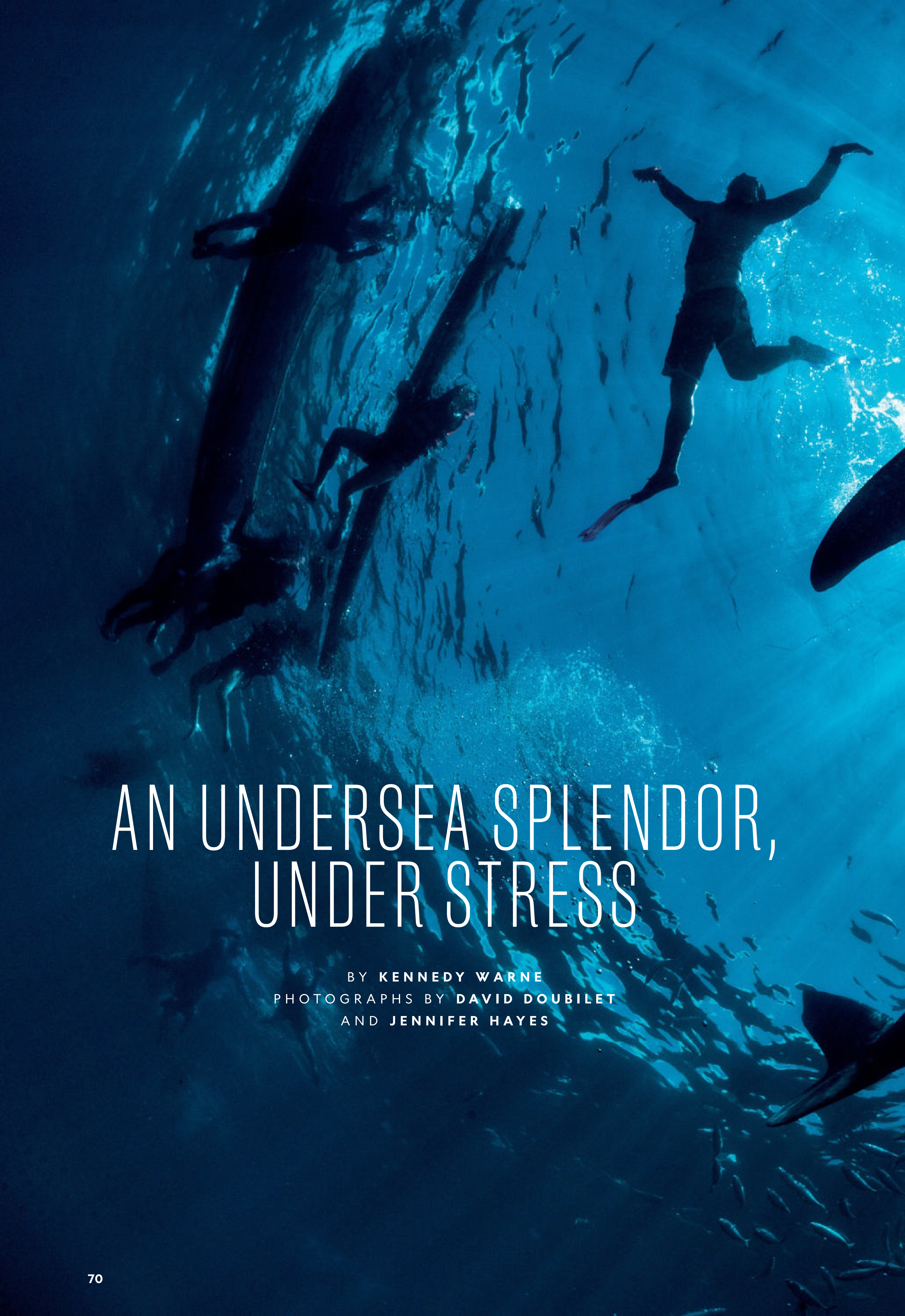
Two years ago, in the early weeks of pandemic lockdown, a pastor told me about his first Sunday services on Zoom. What his congregants missed most acutely, he said, was the passing of the peace—the murmuring of "peace of Christ be with you" and the quick clasp of hands, there in the pews, one person to another. It didn't occur to either of us to wonder just then about the biology of that touch, a two-second deformation of skin cells making humans feel connected to each other and to their God. The neural diagrams now taped to my office walls include many explanatory labels, Receptor Sites and Impulse Conduction and so forth, and when I asked Tyler just how much of this might eventually be replicated by bioengineering—how much of the symphony, via body electrodes and computers?—he corrected me before my question was finished. " 'Replicate' is dangerous," he said. "We struggle a lot with this. We don't have the fidelity to replicate the natural scheme. The general term we use is 'restore.' "

From my Merriam-Webster, the red clothbound edition my grandmother gave me a long time ago: *Restore: to renew, to rebuild, to give back*. Newer dictionaries inhabit my cell phone, but I keep that volume in reach because my palm on its worn cover sends my brain a story it understands. I've watched Brandon Prestwood speak before audiences of scientists; it still makes him nervous, he told me, but he's learned simply to tell them what happened to him and watch them sit up straighter when he reaches the part about feeling Amy's hand.

"In one of the speeches I gave, I talked about the military guy that's been stationed in Afghanistan or whatever for a year," Prestwood told me one of the last times we spoke. This was a hypothetical military guy, you understand, and Prestwood was riffing, imagining where the experimentation might lead. "And before he left, his wife got pregnant, he's never seen his daughter, but he's able to, you know, reach out and touch her via this system somehow. Or the businessman who hasn't been home in six months. The *National Geographic* photographer headed off to the Ivory Coast."

He meant Lynn Johnson, whose images accompany this article and who spent time with the Prestwoods at their home in Hickory, North Carolina. She had mentioned impending work in Africa, Prestwood said, and he was envisioning Johnson, her luggage of the future containing some over-the-counter version of nerve-stimulating electrodes and tactile sensors, with a matching setup at her widowed father's home in Arizona. "Just to be able to give, and receive, the reassuring touch," he said. ☐

Cynthia Gorney is a contributing writer. Her essay on the year in pictures appeared in the January *National Geographic*. **Lynn Johnson** is a longtime contributor who photographed women around the world working to change their communities for the November 2019 issue of the magazine.

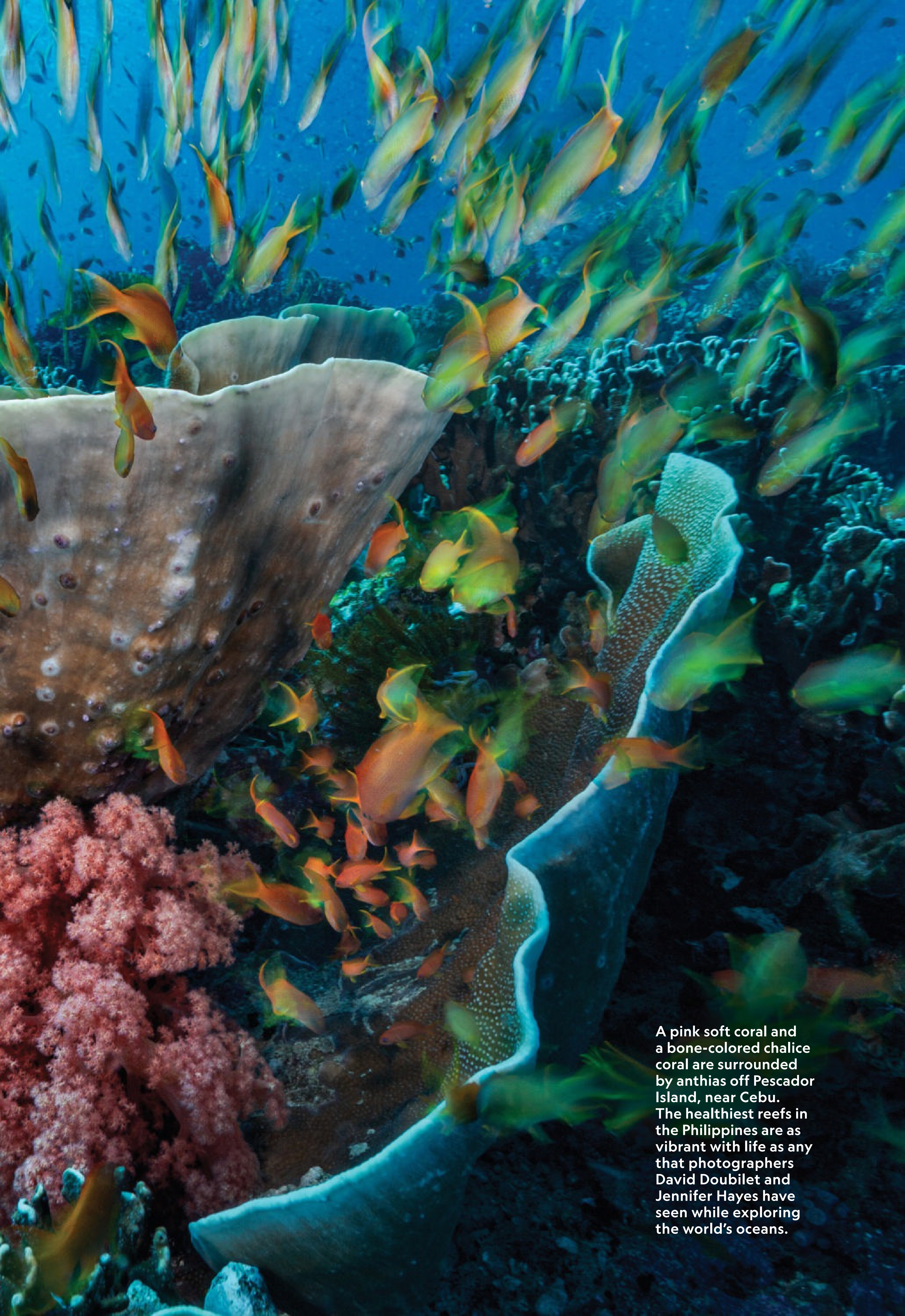


AN UNDERSEA SPLENDOR, UNDER STRESS

BY **KENNEDY WARNE**
PHOTOGRAPHS BY **DAVID DOUBILET**
AND **JENNIFER HAYES**

Tourists swim with whale sharks near Oslob, on Cebu island, reflecting the tension between using and protecting the ocean. Guides toss shrimp to attract the sharks, and scientists worry this could change the animals' behavior. But tourism can replace fishing in the economy, helping preserve coral reefs.

SOME OF THE WORLD'S MOST BRILLIANT
CORAL REEFS ARE PROTECTED BY THE PHILIPPINES.
BUT OTHERS THERE ARE BEING DAMAGED
BY CLIMATE CHANGE AND DESTRUCTIVE FISHING.



A pink soft coral and a bone-colored chalice coral are surrounded by anthias off Pescador Island, near Cebu. The healthiest reefs in the Philippines are as vibrant with life as any that photographers David Doubilet and Jennifer Hayes have seen while exploring the world's oceans.

A hawksbill turtle in Tubbataha Reefs Natural Park in the Sulu Sea stops eating sponges tucked under coral to confront its reflection. The UNESCO World Heritage site, guarded by rangers stationed on a remote atoll, abounds with life.

The National Geographic Society, committed to illuminating the wonder of our world, has funded Explorer David Doubilet since 2012. Doubilet and Jennifer Hayes document both the beauty and devastation in our oceans.

ILLUSTRATIONS BY JOE MCKENDRY

Brown boobies perch on coral near Bird Islet, a rookery in Tubbataha, which is home to more than a hundred seabird species. This critical habitat—the prime breeding ground for brown boobies in the Philippines—is shrinking as climate change causes the seas to rise.

I AM CROSSING A DESERT, BUT NOT ONE MADE OF SAND. I AM SWIMMING THROUGH A WASTELAND OF RUBBLE, THE PULVERIZED REMAINS OF A CORAL REEF. ITS BARRENNESS STARTLES ME.

ELSEWHERE IN THE PHILIPPINES I have been dazzled by jewel boxes of coral splendor. This region of the Indo-Pacific, known as the Coral Triangle, is the planet's richest trove of marine diversity.

More than 500 species of coral are found here—three-quarters of all those known. The reefs they have built would cover an area the size of Ireland. The creatures that live in these submarine cities are beyond counting. The Philippines, the apex of the Coral Triangle, has nearly 1,800 species of reef fish.

Yet this coral graveyard I'm exploring has only refugees. I see a fish called a cleaner wrasse and feel a pang of sorrow. Its role in the reef ecosystem is to clean other fish, nibbling parasites and other marine hitchhikers from their bodies. But this cleaner has no one to clean. It swims in desolate solitude.

The corals around it lie toppled like trees after a hurricane. Among the dead stumps something flashes in the sunlight, and I pick up the bottom of a shattered glass bottle. I have seen bottles like this filled with nitrate fertilizer and topped with a detonator and fuse. Light the fuse, then throw the bottle into the sea. The blast stuns fish or kills them outright, and they float to the surface for fishers to collect.

Blast fishing is deadly for fish and dangerous for fishers. If a bottle explodes too soon, you could lose a hand, an arm, or a life. A fisher died this way two days before I arrived here at the Danajon Bank, 20 miles east of Cebu island, in a region of the Philippines with a long history of destructive fishing practices: explosives, cyanide to flush fish out of coral crevices, nets so fine they catch anything that moves.

All of these methods are illegal, all still in use. They are a cumulative disaster for coral reefs, a more instantaneous depletion of marine life than the slower-burn tragedies of declining fish stocks, pollution, and climate change.

I see a figure in the distance, gleaning in the dynamited ruins, and swim to him. He's wearing a long-sleeved shirt, trousers, and a hood over his head, with holes for his eyes and mouth. He has a battered pair of goggles over his eyes and pieces of plywood strapped to his feet for fins.

"Jellyfish?" I ask, pointing to his hood. My boat driver had told me of tangling with a box jellyfish in these waters. He just had time to scream for help before passing out from the pain of stinging tentacles. He showed me the welts on his arm and stomach, still vivid after 15 years.

"Sun," the diver answers.

To collect enough food for his family, he tells me, he often has to stay out half a day in the burning heat, combing the reefs. He tows a polystyrene box to hold whatever he catches: whelks, abalones, sea urchins, crabs, fish if he's lucky. He uses a hook in one hand and a spear in the other. He pokes, prods, levers, and hacks at the coral. I see a sudden puff of black ink as he spears a cuttlefish.

He picks up a sea cucumber and hands the warty creature to me. A tassel of white threads adorns its rear end. Quicker than I can register, the threads shoot out and wrap around my hand, sticking to my skin like superglue—the animal's reaction to being disturbed. I disentangle the creature, and it goes into the catch box.

The gleaner's laborious search for food is something that is happening across the Philippines, and throughout the Coral Triangle, as ever increasing numbers of people hunt for ever decreasing quantities of fish. For millions of Filipinos, the sea is essential to survival. In the Danajon region, three-quarters of households depend on fishing for food and livelihood. They saw catch rates decline by a factor of 10 in a generation.

A quarter of the fish caught in Danajon come from illegal and destructive practices. Subsistence fishers, living at or below the poverty line, are driven by desperation to use such methods. Filipinos have the phrase *kapit sa patalim,* or "grasp the blade." A desperate person will clasp even the sharp edge of a knife—breaking the law, risking arrest, destroying the reefs that are their lifeline.

In some months of the year, gleaners can gather only about nine meager ounces of seafood an hour from the impoverished reefs. I watch this man suck another breath, flail his plywood fins, and descend.

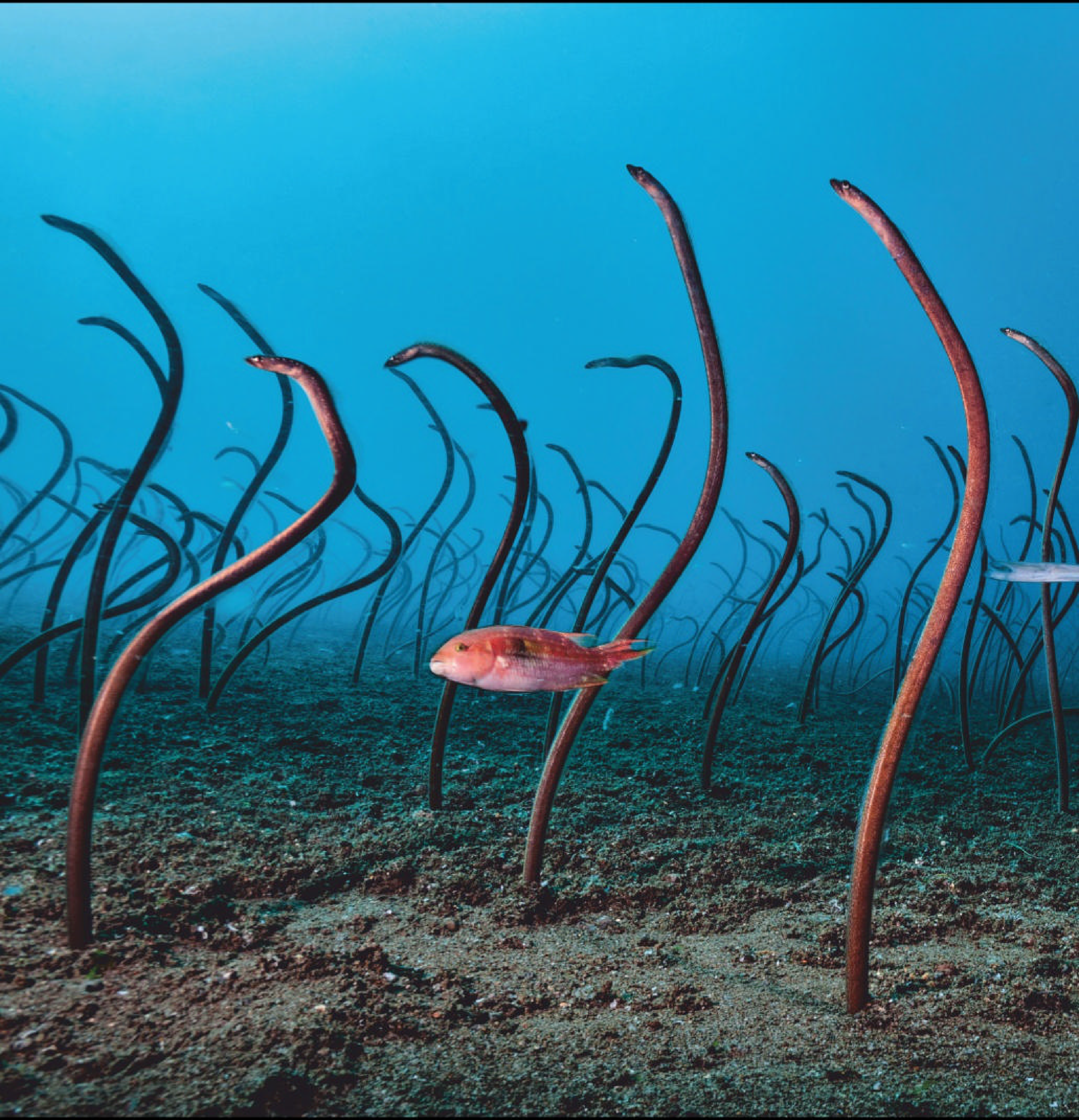
A boat captain frees a bumphead sunfish, also called a mola, from a net. After spending a night in the Verde Island Passage, southwest of Manila, he and his crew of more than two dozen caught only about two bushels of fish, plus the sunfish, which typically is not eaten in the Philippines. Overfishing has depleted some of the archipelago's once abundant waters.

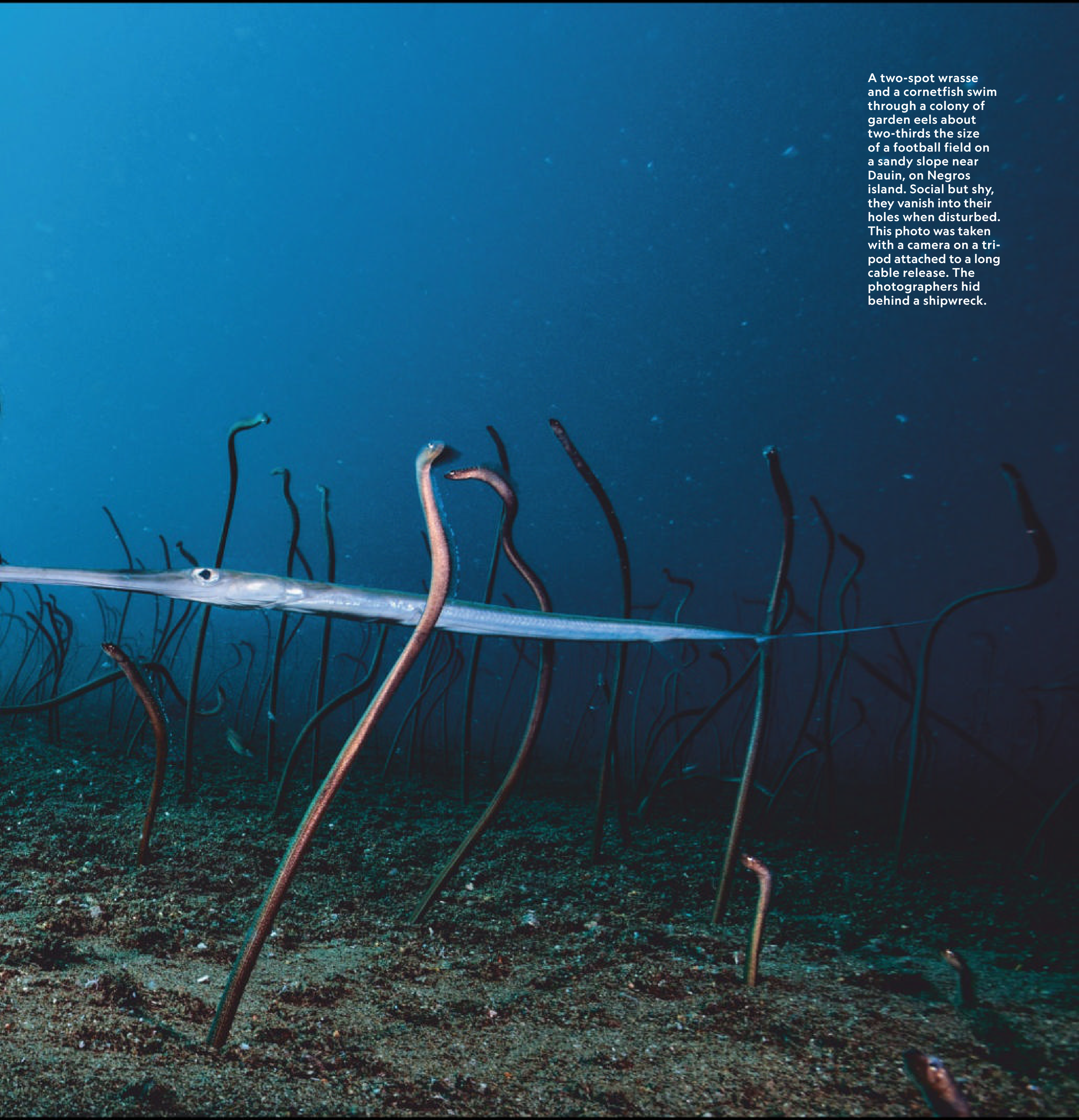
I am gleaning too—hoping to learn how coral reefs might be preserved at a time not just of increasing exploitation but also of human-driven changes in the very ocean itself. Warming seas, acidifying seas, rising seas—these are the darker shadows that fall across the world's coral reefs.

Off the coast of Palawan, the fingerlike island on the western flank of the Philippines, I caught a preview of what's coming. I dived in a sepulchral world of bleached corals. Sea temperatures had exceeded the threshold at which coral polyps part company with the symbiotic algae that give them their kaleidoscopic colors. The corals were ice white. Streams of slime wafted from their dying heads. Even the fish seemed dazed in that monochrome landscape.

Some coral scientists say that mass bleaching events, which used to happen once every few decades, soon may happen every year, as the concentration of atmospheric carbon dioxide continues to increase. What rising sea temperatures don't kill, acidification will. Reefs will reach a tipping point where the carbonate coral structure starts to dissolve faster than it can be formed. When that happens, they will begin to disintegrate. The most diverse ecosystem in the ocean—a planetary feature for 240 million years—will start to disappear.

Can this dystopian story have a different ending? Or at least be delayed? Humans are engaged in the biggest gamble of all time, and the stakes could not be higher.

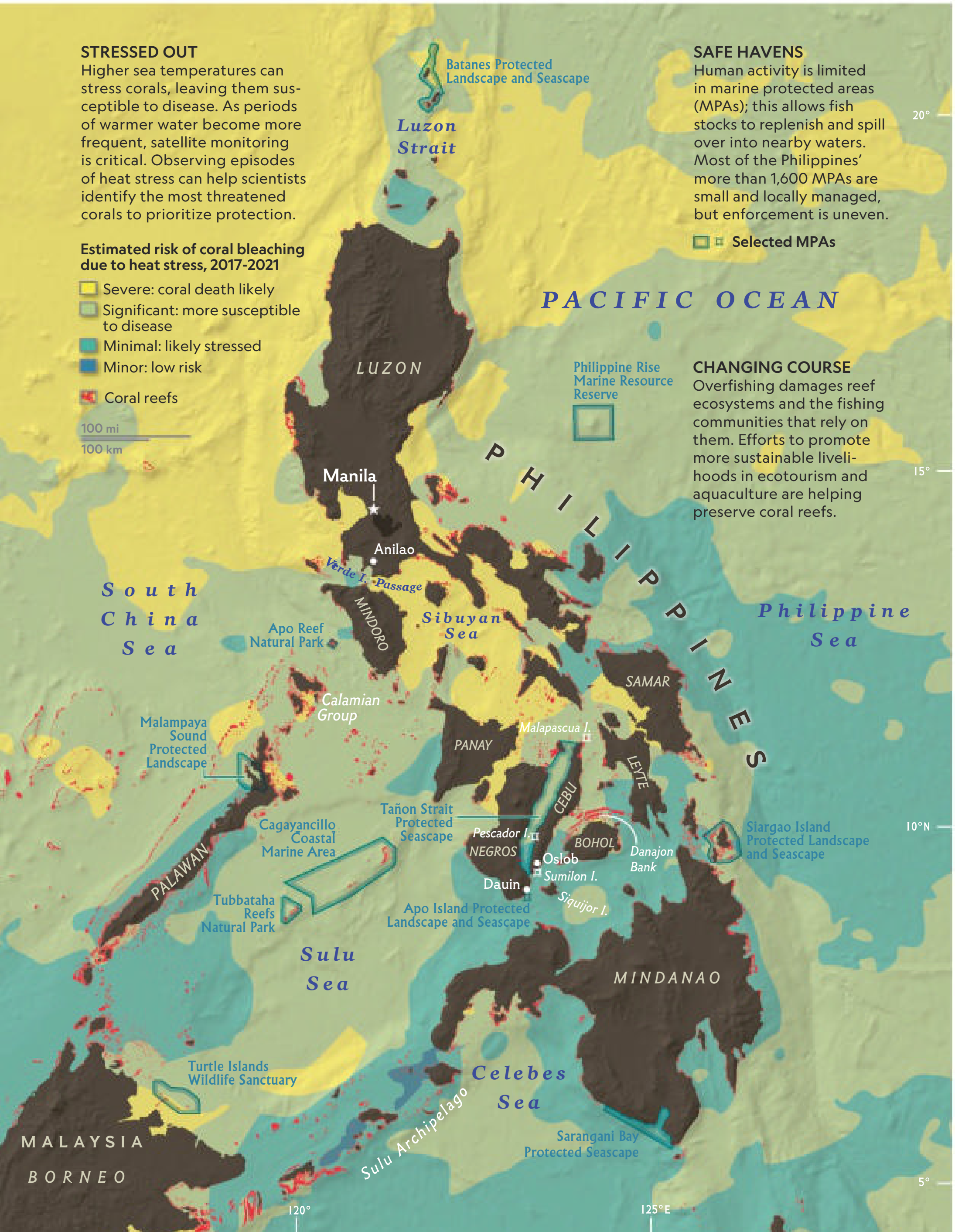




A two-spot wrasse and a cornetfish swim through a colony of garden eels about two-thirds the size of a football field on a sandy slope near Dauin, on Negros island. Social but shy, they vanish into their holes when disturbed. This photo was taken with a camera on a tripod attached to a long cable release. The photographers hid behind a shipwreck.

IN HOT WATER

The coral reefs around the Philippines' islands host a rich array of fish species. Filipinos have protected some of this biodiversity hot spot, part of a region known as the Coral Triangle, but they still face the challenges of warming oceans and a population reliant on the sea for its food and livelihood.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PALAWAN
Tubbataha Reefs Natural Park
Apo Island Protected Landscape and Seascape
Sulu Sea
MINDANAO
Turtle Islands Wildlife Sanctuary
Celebes Sea
Sulu Archipelago
Sarangani Bay Protected Seascape
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STRESSED OUT
Higher sea temperatures can stress corals, leaving them susceptible to disease. As periods of warmer water become more frequent, satellite monitoring is critical. Observing episodes of heat stress can help scientists identify the most threatened corals to prioritize protection.

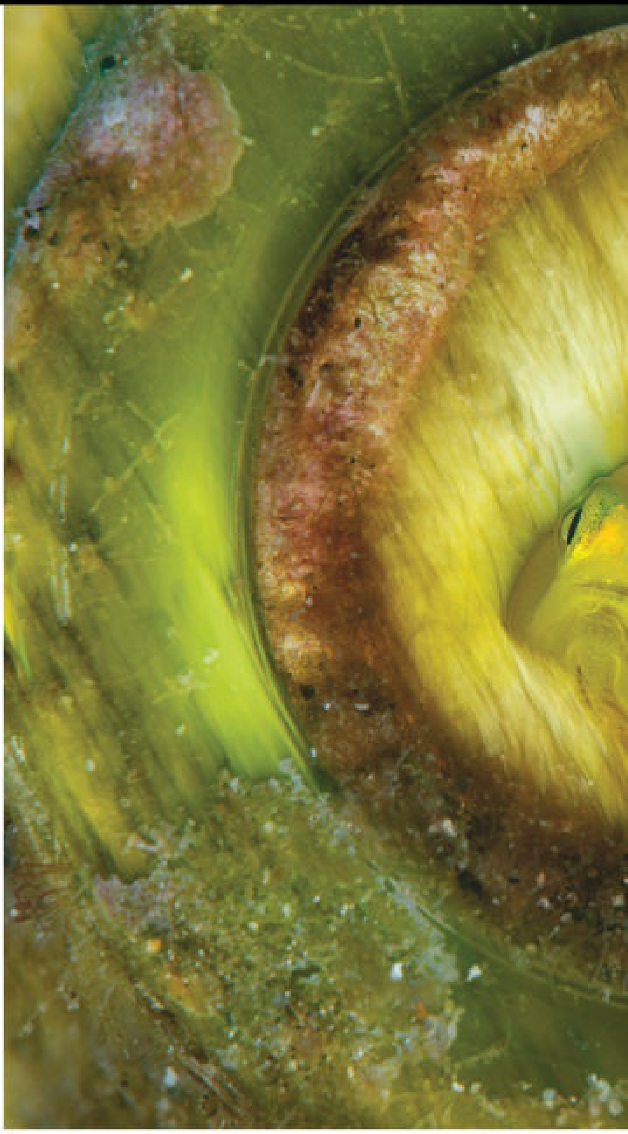
Estimated risk of coral bleaching due to heat stress, 2017-2021

- 🟨 Severe: coral death likely
- 🟩 Significant: more susceptible to disease
- 🟦 Minimal: likely stressed
- 🟦 Minor: low risk
- 🟥 Coral reefs

SAFE HAVENS
Human activity is limited in marine protected areas (MPAs); this allows fish stocks to replenish and spill over into nearby waters. Most of the Philippines' more than 1,600 MPAs are small and locally managed, but enforcement is uneven.

☐ ▫ **Selected MPAs**

CHANGING COURSE
Overfishing damages reef ecosystems and the fishing communities that rely on them. Efforts to promote more sustainable livelihoods in ecotourism and aquaculture are helping preserve coral reefs.



THERE ARE TWO WAYS to respond to a diminishing resource: Ease up or double down. Filipinos have done both. The bomb-cratered moonscape I saw at Danajon Bank is the end result of one approach: destructive overfishing of reef ecosystems. But at Dauin, a municipality on Negros island, I saw a different legacy, one of reef protection that has eased pressure on marine life and sustained a living for communities on the coast.

The approach was pioneered by Angel Alcala, a Filipino biologist who has championed the creation of small, community-managed marine protected areas (MPAs). Often the prime reason for creating these sanctuaries is to preserve biodiversity, but for Alcala the main focus is

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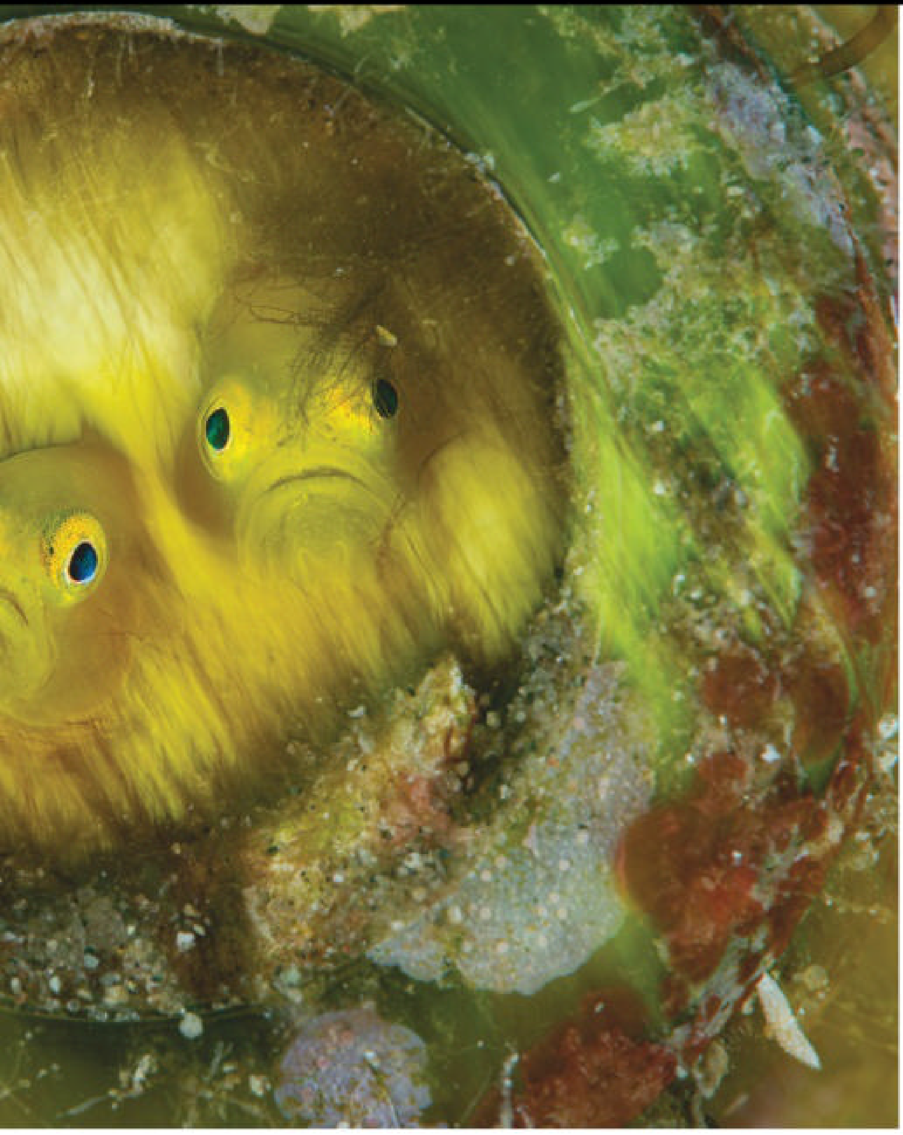
ROSEMARY WARDLEY AND PATRICIA HEALY, NGM STAFF. SOURCES: GENERAL BATHYMETRIC CHART OF TH
CONSERVATION INSTITUTE; NOAA CORAL REEF WATCH; CORAL TRIANGLE ATLAS; AARON N. RICE, CORNE



A pair of golden gobies peer from inside a glass bottle that they've made their home, off Anilao, south of Manila. The algae around them appear blurry because this photograph was made with a long exposure. Found items on the sandy bottom are quickly colonized. Heavy rains wash trash from cities into the ocean. What doesn't sink can become floating islands of debris.

fisheries. “Filipino people are fish-
cala tells me when I meet him at the
enter he leads at Silliman University,
of Dauin. “To maintain that, there
e marine reserves.”

started in the early 1970s with two
e reserves: one near an island that
ited (Apo, off the coast of Dauin) and
an island that was not (Sumilon, near
forms of harvesting were prohibited.
ults were spectacular. In 10 years, fish
or some species in the sanctuaries—
oupers, snappers, and jacks—increased
kfold. As the density of fish inside the
ncreased, fishers reaped the benefit
the phenomenon of spillover: Fish “spill over” reserve boundaries into waters where they can be legally caught. The idea that no-take sanctuaries could replenish fish stocks on nearby exploited reefs offered a bright speck of hope in an otherwise dismal outlook for coastal fishers.

Apo Island's success caught the attention of Rodrigo Alanano, who was elected Dauin's mayor in 2001. Alanano decided to increase the number of marine protected areas along the Dauin coastline. He could do this because municipalities have jurisdiction over their coastal waters out to 15 kilometers, or 9.3 miles.

I ask him how he persuaded subsistence fishers to give up a portion of their traditional fishing grounds. “I told them we needed to have breeding grounds as well as fishing grounds,” he says. “I told them, ‘If you have a sanctuary, populations will grow, and some fishes will get out of the sanctuary and those ones are for you. The reserve will be a breeding ground for fishes now and forever, for you and for the future.’ Later on, I told them, it would become a diving spot, and there would be an income from that.”

Still, getting fishers to accept an immediate loss for an uncertain gain was no easy matter, and many coastal dwellers opposed the sanctuaries. Alanano was served with lawsuits and received death threats. He shrugs at the memory. “When I became mayor, I gave my life for this profession,” he says.

“What made you so passionate?” I ask. “You're not even from a fishing family.”

“I am a mining engineer,” he replies. “I worked for mining companies for 12 years before entering politics. We destroyed mountains. We used toxic chemicals that flowed out to sea. I am an experienced destroyer of the environment. I am licensed to destroy. What I experienced is that once you destroy the environment, no human being can put that right again. It cannot be put back for your children. And when you kill the last fish, you will realize you can't eat money.”

His arguments prevailed. During Alanano's nine years as mayor, he increased the number of MPAs along Dauin's coastline from four to 10. I dived in some of them. Though small, they protect wondrous creatures. At one site I watched scores of slender garden eels rise from their holes in the seabed and sway as if hearing the music of a snake charmer.

As Alanano foresaw, such sights are a drawing card for tourists, and Dauin has become a popular dive destination, as have dozens of other sites across the 7,641 islands in the Philippines. Most of Dauin's MPAs are referred to by the names of fish species that serve as their celebrity attractions: Nemo/Clown Fish MPA, Mandarin MPA, Frog Fish MPA, Ghost Pipe and Sea Horse MPA.

As tourism has flourished, fishers have seen opportunities to switch from catching fish to providing services. In Oslob, a town on the coast of Cebu, few members of the fishers association fish anymore. They earn a handsome living enabling tourists to swim with whale sharks. Near Puerto Galera, on the island of Mindoro, I watched snorkelers being towed out to see giant

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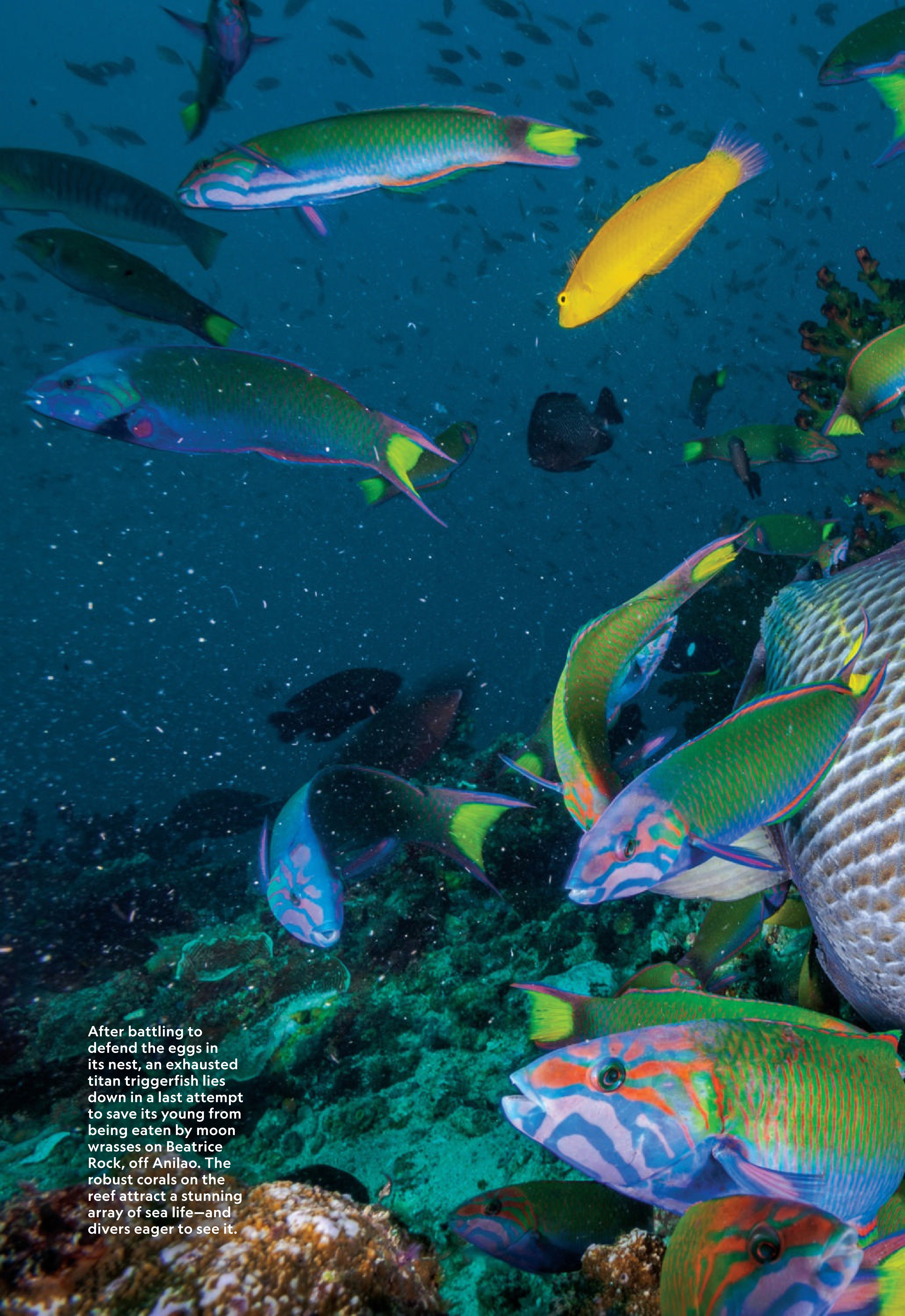


After battling to defend the eggs in its nest, an exhausted titan triggerfish lies down in a last attempt to save its young from being eaten by moon wrasses on Beatrice Rock, off Anilao. The robust corals on the reef attract a stunning array of sea life—and divers eager to see it.

A blizzard of orange scalefin anthias rises in the strong currents of the Verde Island Passage to feed on plankton. The nutrient-rich strait, which separates the islands of Luzon and Mindoro, is one of the most productive marine ecosystems in the world, as well as a busy shipping lane leading to Manila.

clams by fishers in small outrigger canoes powered by chain saw and lawn mower engines.

In Dauin, several fishers have retrained as dive masters. Amado A. Alar II runs Bongo Bongo Divers, down a side road from a Chooks To Go fried-chicken house. He tells me that when Dauin's MPAs were being established, some fishers refused to accept the loss of their fishing grounds. They cut the ropes of the buoys that marked the sanctuary boundaries, slipped into protected areas at night to catch fish, and came to blows with the *bantay dagat*—municipally appointed sea wardens—if they were caught.

But when the fishers saw their catches increase, they changed their tune. "Slowly, slowly the people understand—'Ah, that's why it is like this,'" Alar says. "Now they will protect the sanctuary if they see someone fishing there. They understand that we have a nursery here."

This nursery effect is now considered one of the key benefits of MPA networks. Larval fish disperse from reefs in protected areas to unprotected reefs, providing replenishment.

Rene Abesamis, one of Alcala's colleagues at Silliman, has studied the process in Dauin's MPAs. He chose the vagabond butterflyfish for his research and found that its larvae can drift up to 23 miles in monsoon winds and strong currents before settling into a new reef habitat.

Knowing that fish on the local reef may have come from neighboring sanctuaries has a powerful effect on people. "It tells them that they are

Pink anemonefish tend to their host anemone, where they make their home, while a camouflaged tasseled scorpionfish lurks nearly invisible beneath the coral near Sumilon Island. Scorpionfish are masters of disguise, waiting to ambush prey such as anemonefish at the right moment.

part of the same ecological network, even if they belong to different municipalities," Abesamis says. "It tells them their efforts are connected."

Mutual replenishment is the logic behind efforts to scale up MPAs into a nationwide network. Philippine law stipulates that 15 percent of coastal municipal waters must be protected within no-take MPAs. There are now more than 1,600 of them throughout the country. Unfortunately, most are tiny and not well managed—mere "paper parks."

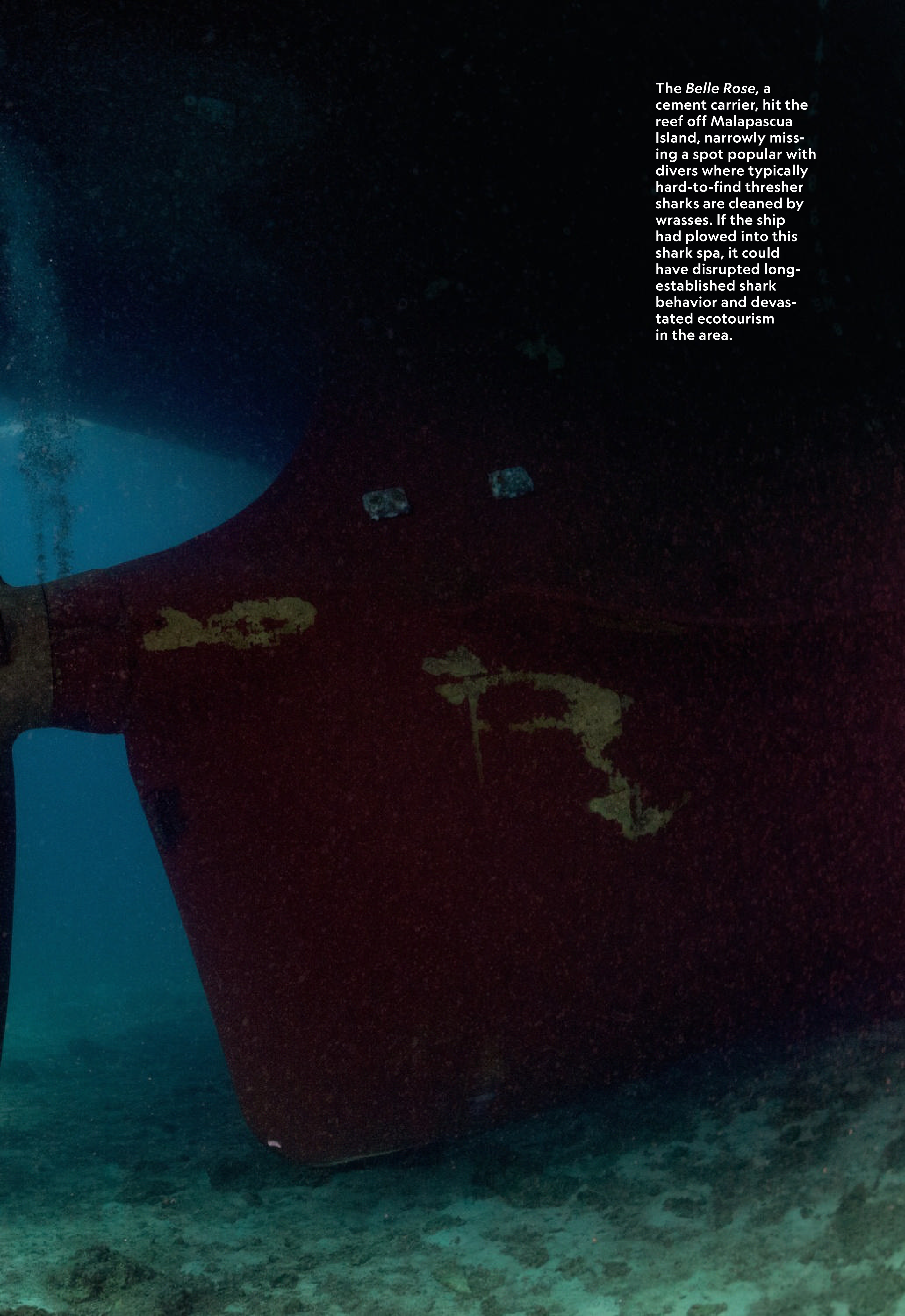
Only 3 percent of the country's coral reefs are protected, Alcala says, explaining, "We need 20 to 30 percent. It's a question of empowering local communities." And giving them the resources to protect the investment they have made. Even sanctuaries that are properly cared for by their communities are susceptible to poaching. The COVID-19 pandemic, which has devastated tourism, also has made marine protections precarious. Even local people, grasping the blade of desperation, have entered protected areas to feed their families.

BUT POACHING BY OUTSIDERS is a greater threat, and a growing problem across the Philippines. With fast boats and scuba gear, professional poachers can strip a sanctuary in a night, Darrell Pasco tells me. Pasco works in coastal resource management for the island of Siquijor, a dozen miles from Dauin. One of Siquijor's MPAs was poached four times in a single year. The intruders come at night, during fiestas, or at times of bad weather, when there are fewer eyes watching, he says. They carry weapons. How can Siquijor's bantay dagat, who earn a pittance, oppose such people?

Siquijor, as much as anywhere else, needs marine sanctuaries to bolster the island's fisheries. As high-value fish such as grouper and snapper have become scarce, species that were formerly considered trash fish have become standard fare. Damselfish—darting cobalt-blue beauties with mango dipped tails—were never eaten, Pasco says. Now they sell for a premium in the market, alongside such delicacies as sea anemones cooked in coconut milk, spider conchs, sea cucumbers, sea urchins, and seaweeds that look like clusters of green pearls.

I saw the struggle that Siquijor's fishers face when I slipped into the silky sea one morning to watch a group of men haul up a fish trap, or *bubu,* from the seabed about 250 feet below us. Slowly it rose, a 15-foot-long woven basket spacious enough that I could have swum pirouettes inside it. The pattern of its bamboo weave was intricate, the work of skilled hands. As seven men heaved the bubu onto the deck of their *banca*—the traditional double-outrigger boat of the Philippines—I peered inside, looking for the harvest that should have been there, for the baited trap had lain on the seabed for a week. A fisherman reached in and lifted out a single triggerfish—a paltry return for a week's deployment.

The next bubu I watched being hauled up had no fish at all. *"Mingaw,"* one fisherman called, as the trap broke the surface. Empty.



The *Belle Rose,* a cement carrier, hit the reef off Malapascua Island, narrowly missing a spot popular with divers where typically hard-to-find thresher sharks are cleaned by wrasses. If the ship had plowed into this shark spa, it could have disrupted long-established shark behavior and devastated ecotourism in the area.

Distinctive silhouettes of red-toothed triggerfish hover above a river of juvenile convict blennies flowing over a coral reef in the Verde Island Passage. Despite overfishing and pollution, this area of the Philippines still retains tremendous biodiversity.

I winced as small jellyfish and broken arms of sea anemones fell from the trap and stung my skin. And I winced for the dashed expectations of the men and their families. Bubu fishers may earn as little as a dollar per trap per week. Their households are typically on the poverty line or below it, as is 60 percent of the country's coastal population.

Like Dauin's mayor, Pasco has been threatened over his efforts to expand MPAs and deter poaching. To guard his property, he keeps a watchdog and sleeps in a hut outside his house. "I'm afraid for my security and my family's security, but I'm still doing my job," he tells me.

There is no other option, he says. "We have to give an honest and profound education for every Filipino, that it is up to us to take care of the ocean because we get almost everything we need from the ocean. If we don't do that, the time will come when we will have no more fish to catch, and we will only see fish in books and on the internet, not in the ocean."

Tourism helps alleviate pressure on dwindling fish stocks, but not every place can be a dive hot spot. Another way of relieving the demand on reef ecosystems is for fishers to take up alternative livelihoods such as marine farming. At a remote atoll in the Sulu Sea I met families living on bamboo platforms in reef lagoons, drying seaweed. The algae they farm produce carrageenan, a polysaccharide used as a stabilizer in medicines, toothpaste, pill capsules, cosmetics, and

other products. Thousands of Filipino families have become seaweed ranchers.

In the islands of the Calamian Group, at the northern tip of Palawan, people are learning how to ranch sea cucumbers. I helped release dozens of juveniles the size of my little finger from net cages so they could free-range across warm estuarine flats. In two months they will reach the size of fat sausages. When dried, sea cucumbers sell for more than $30 a pound, 10 times more than grouper.

THERE IS ABUNDANT EVIDENCE that reefs regenerate when human pressure is removed. The preeminent dive site in the Philippines is Tubbataha Reefs, a national park and UNESCO World Heritage site in the center of the Sulu Sea. Here I saw barrel sponges large enough for a person to curl up inside. I watched confetti clouds of fish—orange, purple, green, yellow—floating above slender coral branches, while gray reef sharks slept on coral sand beneath. An octopus unspooled its arms and, with an instantaneous color change from fawn to charcoal, jetted away. Exceptional today, these reefs were all but destroyed by blast fishing in the 1960s. Strict enforcement of no-take rules has redeemed them.

But will they survive bleaching and other climate pressures? Most researchers think not. It is projected that by 2050 more than 90 percent of the Coral Triangle's reefs will be critically threatened by climate impacts. As reefs fail, food insecurity in the region will become calamitous. How will coastal dwellers survive?

The Philippines has stared into an apocalyptic future of degraded reefs and depleted seas. It has recognized the choice it has to make: Seize the moment of change, or grasp the blade of crisis. In the past four decades, communities have made hard choices to forgo fishing everywhere for the ability to catch fish somewhere. They have realized that visitors will pay to see thriving reefs. They have become committed guardians and stewards of an incomparable ocean realm.

But these changes alone will not preserve the reefs on which millions depend. Ocean warming is locked in. Ocean acidification is locked in. Extreme weather is locked in. What will local efforts avail in the face of intractable planetary forces?

I ask coral reef biologist Wilfredo Licuanan, a professor at Manila's De La Salle University, what reason he or anyone could have for optimism.

"We have to delay the inevitable long enough for some glimmer of hope, some solution that might come up that is not yet visible," he says. "I want to be able to at least look my students in the eye and say, 'I'm trying.' I'm pessimistic, but I'm trying. If I fail, I don't give up. I try again."

Yes, we keep trying. This is how we sustain hope in a threatened world. ☐

Kennedy Warne wrote about conservation in the Seychelles in the March 2016 issue. **David Doubilet** and **Jennifer Hayes** photographed sea creatures at night for the October 2021 issue. All three are veteran *National Geographic* contributors.

TWO DECADES AGO IBERIAN LYNX WERE NEARING **EXTINCTION.** NOW THE CATS ARE **REBOUNDING,** THANKS TO CAPTIVE BREEDING IN SPAIN— AND THE ANIMALS' KNACK FOR **AVOIDING PEOPLE.**

THE COMEBACK CATS

BY **CHRISTINE DELL'AMORE**
PHOTOGRAPHS BY **SERGIO MARIJUÁN**

Wildlife underpasses, such as this one below a highway connecting Andalusia with Madrid, help lynx move through their territory safely. They have surprised researchers by learning to live near people, such as in neighborhoods and commercial olive groves—mostly by staying out of sight.

PREVIOUS PHOTO

A lynx emerges from the trees in Sierra de Andújar Natural Park, a species stronghold in southern Spain. Fondly dubbed the Iberian jewel, lynx live in five isolated populations across the Iberian Peninsula's Mediterranean scrublands.

At an abandoned farm, kittens play with the remains of a rabbit while their mother, Odrina (at far right), watches. Scientists name most of the babies after Spanish nature and folklore. Odrina—whose name refers to a traditional leather bag that holds wine or oil—was born here in 2017 and has returned to raise her own kittens, an example of the species' ability to capitalize on human-made environments.

IN JUST 20 YEARS, THE IBERIAN LYNX HAS GONE FROM THE WORLD'S MOST ENDANGERED FELINE TO THE GREATEST TRIUMPH IN CAT CONSERVATION.

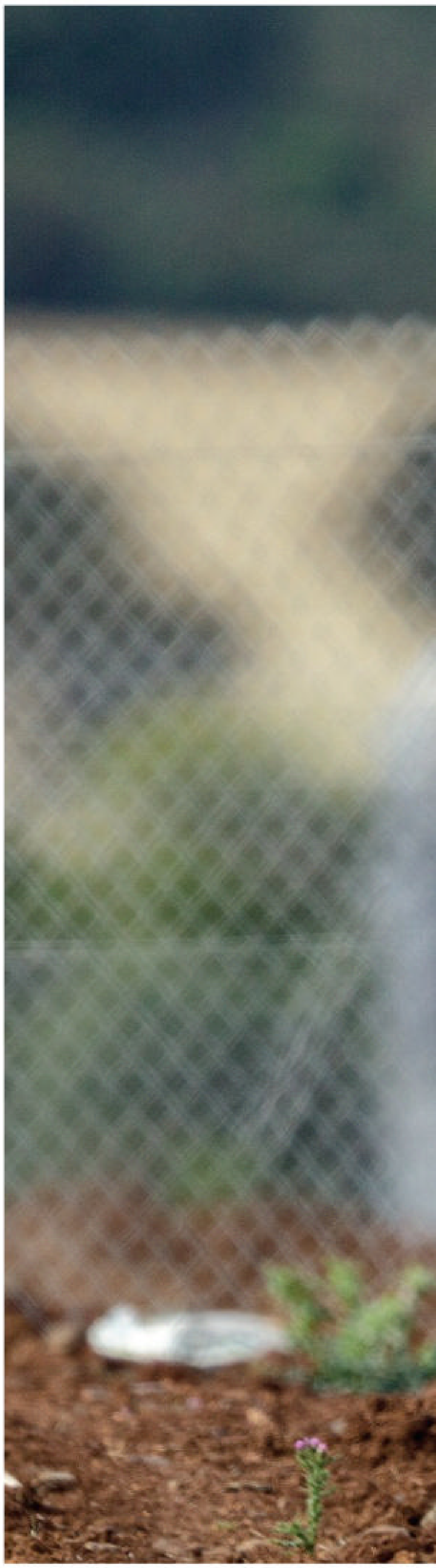
In 2002 fewer than a hundred of these bobtailed, golden-eyed predators slunk through the Mediterranean scrublands of the Iberian Peninsula. Since then, the population has grown tenfold, with at least 1,100 animals scattered across Spain and Portugal.

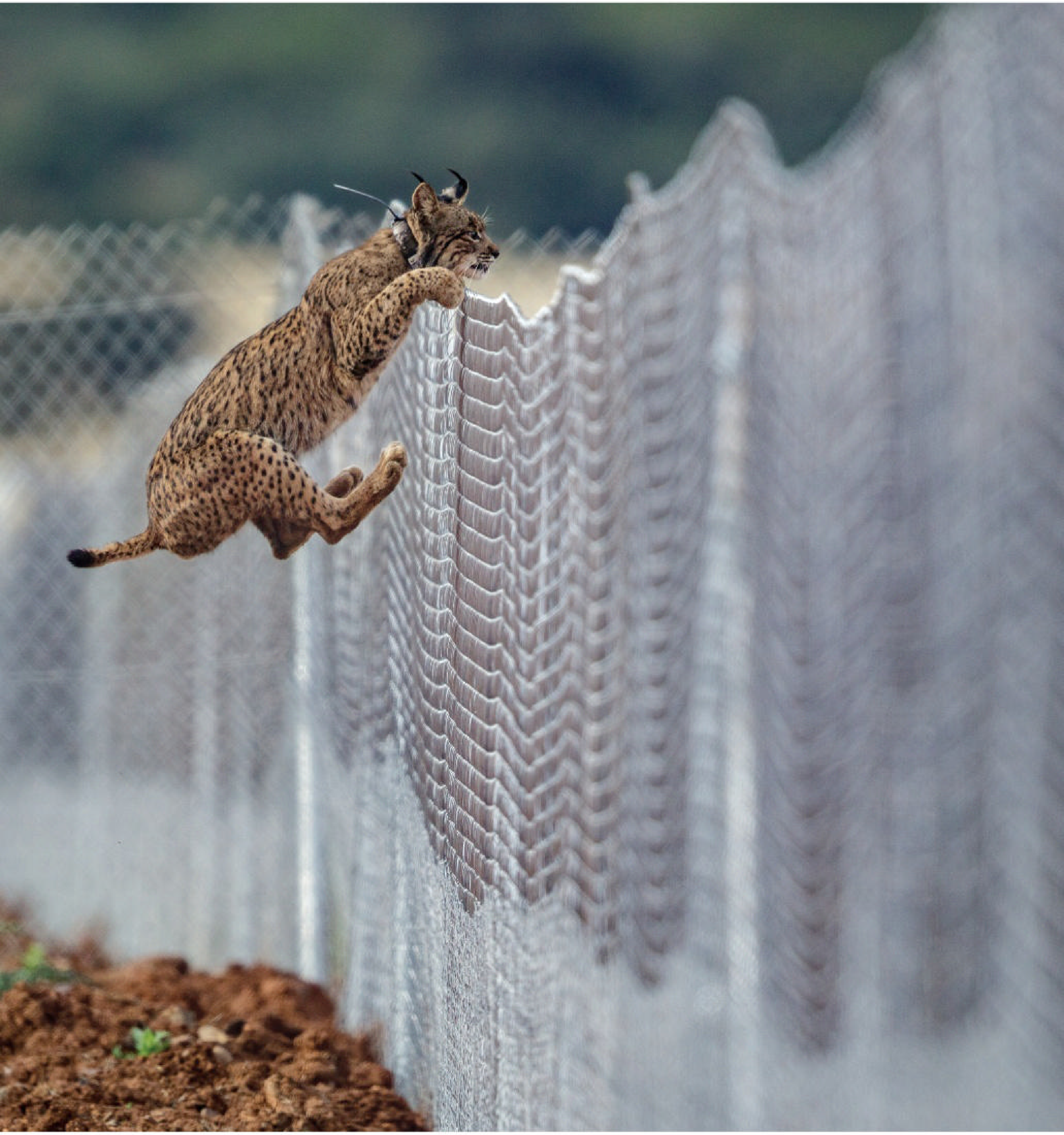
The dramatic turnaround is the result of the all-out effort to breed the cats in captivity, the lynx's status as a natural treasure, and the animal's innate scrappiness, which has surprised even conservationists.

When the European Commission's Life program first brought together more than 20 organizations in 2002 to rescue the lynx, the species had all but disappeared. Widespread hunting and a virus had wiped out most of the peninsula's European rabbits, the lynx's main prey.

Lynx breed easily in captivity, however, and most of the animals that eventually were reintroduced into carefully chosen habitats throughout Spain and Portugal have thrived. Near one main release location, around southern Spain's Sierra de Andújar Natural Park, Iberian lynx have even learned to live in neighborhoods, in commercial olive groves, and around highways—mostly by avoiding people. One mother lynx managed to hide her newborns in a house where people were throwing a party.

Such adaptability boosted their numbers, and by 2015, the International Union for Conservation of Nature (IUCN) had reclassified the lynx's status from critically endangered to endangered.





A radio-collared lynx named Milvus easily leaps a fence into a rabbit research area run by WWF Spain in eastern Sierra Morena. Staff later fortified the fence with electricity to block Milvus—and other "cheeky" lynx, as photographer Sergio Marijuán describes them. An adult lynx needs to eat a rabbit a day to survive; a mother with kittens needs three.

When a virus wiped out most of the region's rabbits in the 1990s, lynx numbers dropped sharply. Today conservationists capture rabbits in places they're not wanted, such as at this vineyard near Sierra de Andújar park, and take them to lynx habitats where rabbit populations are low. This strategy of supplementing rabbit numbers in lynx habitat builds a robust source of prey in the event of another virus outbreak.

"The lynx is a symbol of Iberian nature, and its conservation was the responsibility of all of us. Thanks to the work carried out over the last 20 years, it is now also one of the greatest examples of successful conservation worldwide," says Francisco Javier Salcedo Ortiz, regional coordinator of the Iberian lynx recovery plan for Andalusia, an autonomous state in southern Spain.

But the cat's not out of danger just yet. Its thousand-square-mile territory is a collage of five—soon to be seven—isolated groups. For Iberian lynx to fully recover, they must be able to roam from one group to another, ensuring the species' long-term health by diversifying gene pools.

That's why the next stage of the Life project, Life LynxConnect, which was launched in 2020, will focus on creating at least 10 wildlife corridors—six-square-mile tracts of rabbit-rich habitat that the scientists call stepping-stones—to act as passageways among the existing lynx groups. Scientists selected these habitats based on predictions of where lynx are most likely to travel. For instance, lynx prefer to take the shortest paths through undeveloped and intact habitats, such as natural forest, and avoid broken-up parcels of farmland.

This year the $21 million project and its partners will begin establishing these stepping-stones and reintroducing lynx to two new Spanish locations, in Granada and Murcia.

For Iberian lynx to fully recover, they must be able to roam from one group to another. That would ensure diversified gene pools.

Ideally, these interventions will boost the number of breeding females to 750 on the Iberian Peninsula by the end of 2040, at which point the species would be much less vulnerable to extinction, according to Salcedo.

"It's an ambitious objective, but it is necessary," he says.

IN THE MID-20TH CENTURY, well-known Spanish TV personality and naturalist Félix Rodríguez de la Fuente dubbed the lynx the "Iberian jewel."

This long-standing public fondness for the cat helped local governments, nonprofits, and private individuals lobby the European Union successfully to fund the lynx's recovery. At more than $90 million to date, it's one of the biggest conservation investments ever made on the continent.

"If you walked up to someone in Madrid, they would say they are proud of the lynx," says Nuria El Khadir Palomo, managing director of the Madrid-based Foundation for the Conservation of Biodiversity and its Habitat, one of the Life LynxConnect project partners. Palomo and her colleagues advise the partner groups on how best to use their allocated lynx-conservation budget. They also study lynx habitats throughout Spain to determine which areas can support the animals.

The cat is popular, even among farmers and landowners, but a few view lynx as pests and occasionally will poison or trap them for supposedly harming livestock. Illegal killings make up nearly 25 percent of annual lynx deaths on the peninsula, the second highest cause of nonnatural death, after vehicle strikes. Furthermore, hunting has deep roots in southern Spain; hunters historically have killed lynx for sport and have seen the predators as competitors for their favorite quarry, rabbits.

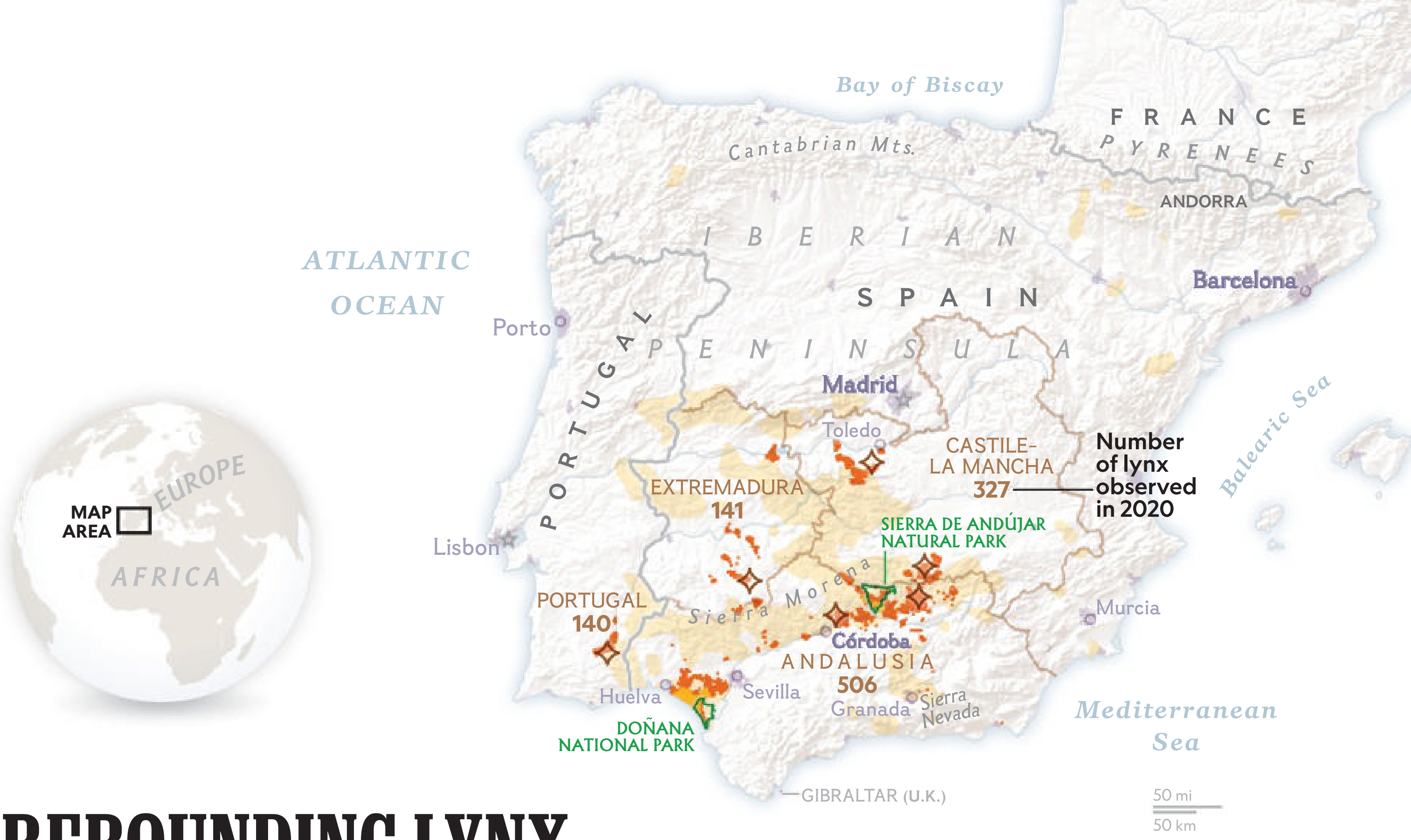
That's why education is the "best tool to improve the lynx population," says Maribel García Tardío, lead technician for Andalusia's Iberian lynx recovery plan. She and her colleagues regularly meet with landowners and hunters, explaining how lynx rarely kill larger domestic animals, such as lambs, and will displace red foxes and other carnivores that are more likely to prey on these animals.

This outreach has paid off. Many landowners have launched tourism ventures that offer visitors the chance to see the bushy-bearded feline in the wild.

Conservationists also are working to reduce

REBOUNDING LYNX

Endemic to Spain and Portugal, the Iberian lynx was nearly extinct 20 years ago because of overhunting, habitat fragmentation, and rampant disease in its favored prey, the European rabbit. New lynx populations remain isolated, but conservation and reintroduction efforts have increased lynx numbers tenfold, to more than 1,100.



Range of Iberian lynx *(Lynx pardinus)*

▨ 1960 ▨ 2002 ▨ 2019–2020

◇ Reintroduction site ▨ Urban area

CHRISTINE FELLENZ, NGM STAFF. SOURCES: CENSO DE LINCE IBÉRICO; LIFE+IBERLINCE PROJECT; LIFE LYNXCONNECT/JUNTA DE ANDALUCÍA

vehicle strikes by installing highway underpasses for wildlife, road warning signs, and speed bumps in areas where lynx often are killed. The cats quickly figure out how to use the underpasses—another example of their adaptability—and data show these interventions have reduced deaths, according to García Tardío. But as lynx expand their territories and grow in number, roadkills likely will become a bigger problem, she says.

There's also always the fear that another rabbit virus will emerge, Salcedo says—one more reason it's important to have a widespread, interconnected population of animals. For now, however, the cats' scattered and isolated groups remain the biggest threat to the species' recovery.

THE IBERIAN LYNX is one of 33 small-cat species, many of which are endangered or threatened. These animals have long been eclipsed by their bigger, more famous cousins such as lions and tigers, but lately people have begun to recognize the world's little-known undercats, says Jim Sanderson, program manager for small-cat conservation at Re:wild and a member of the IUCN Cat Specialist Group, which helped support and advise the Iberian lynx's rescue efforts.

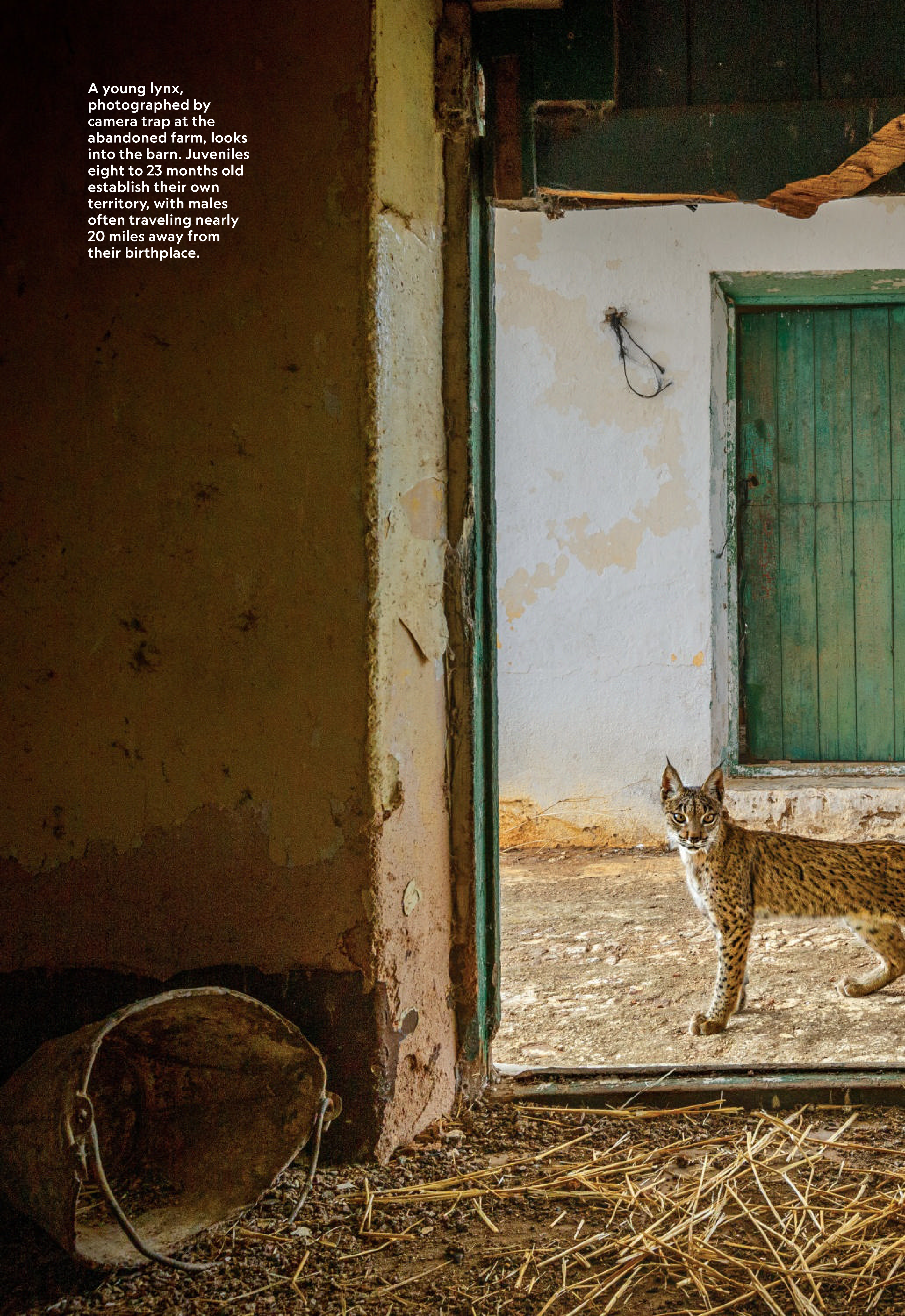
Sanderson says that 2020 was the "best year ever for small-cat conservation. It was like we reached a tipping point, and all the sudden financial partners stepped up."

The U.S.-based nonprofit Panthera runs a small-cats program, for example, and the number of informal working groups dedicated to saving little cats worldwide has jumped from two to 12, Sanderson says.

The Iberian lynx, he adds, should be the inspiration for them all.

"If we did nothing else," Sanderson says, saving the lynx "would stand out as the highlight in my mind." □

Senior editor **Christine Dell'Amore** wrote about underappreciated endangered species in the May 2021 issue. Award-winning Spanish photographer **Sergio Marijuán** has been fascinated by lynx since meeting a captive-bred pair in Andalusia in 2017.



A young lynx, photographed by camera trap at the abandoned farm, looks into the barn. Juveniles eight to 23 months old establish their own territory, with males often traveling nearly 20 miles away from their birthplace.

COLD-WATER RUNS OF TROUT, SALMON, AND OTHER FISH ARE BEING OVERHEATED BY CLIMATE CHANGE, HITTING FISHERS RIGHT WHERE THEY SPEND THEIR BEST DAYS.

BY **CHRISTOPHER SOLOMON**

PHOTOGRAPHS BY **KHOLOOD EID**

ANGLING TO SAVE A PASTIME

Chad Brown shows Stephen Green (front) how to fly-fish on the Clackamas River near Portland, Oregon. Brown leads Love Is King, an organization that empowers people of color to feel welcome in the outdoors. The number of Black fishers in the United States is growing.

PREVIOUS PHOTO

Brook trout prepare to spawn in fall in a northwestern Virginia stream. They're the state fish—but climate change threatens the cold water they need.

A Trout Unlimited team drains Upper Independence Creek, in the Sierra Nevada. To preserve a rare native population of Lahontan cutthroat trout, the team is culling intruders: hybrids carrying the genes of rainbow trout. Until the 1960s, California stocked nearby Independence Lake with such non-native fish.

THE MIDDLE FORK of the Flathead River is born in the high, rocky country of western Montana, near the roof ridge of North America. For dozens of miles it rolls through green wilderness, taking in the snowmelt from Muskrat Pass and Slippery Bill Mountain and a half dozen creeks as it grows into one of the beloved waterways of the American West.

On a warming midsummer morning, the waters curled like a cat around the shins of a short woman wearing polarized sunglasses and a trucker's hat pincushioned with fishing flies. Hilary Hutcheson is a fly-fishing guide and climate activist who speaks to audiences across the nation. Her summer fishing season in western Montana is brief, which means frenetic, and by late July her voice, lightly scuffed at the best of times, sounded as if it were being played through old speakers.

"It's almost Angry August, when all the guides get a little twitchy," she told me. "The nights are just naps and the days are just packed. We say that we sleep in December." Still, any chance to be on the water put her in a good mood. She pushed off and took the oars, nosing the bow of the fishing raft into the current.

The day was yellow and warm. Cobbles colored the pale pink and faded green of old church fronts lined the shore. The river held the stones and sky and the fish within it as if in a jewel box. Hutcheson, 44, grew up here on the rivers of the Flathead region. She knows them better than almost anyone. Frequently she edged the raft out of the current, dropped anchor, and suggested we study the water together and consider what it told about where one of its handsome cutthroat trout lingered, feeding, beneath the surface. Only then would she tell me to cast to the fish. On a day like this, with the beer cold in the cooler and the air taut with hope, it was hard to believe anything could be wrong in the world.

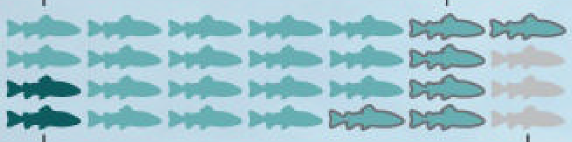
Fly-fishing guide Hilary Hutcheson (center) and daughters Ella (at left) and Delaney stand in the Middle Fork of the Flathead River, near their home in Montana. Watching climate change affect the river impelled Hutcheson to activism. She has lobbied government officials to get them to address the problem.

THE ORVIS CO.

TROUT TROUBLES

Climate change is depriving native freshwater trout of the cold, continuously flowing water they depend on. It's warming the waters of streams and lakes in most U.S. states, intensifying drought, and reducing mountain snowpack in the West. But what harms native trout has proved a boon for invasive fish—many of which thrive in these quickly warming waters.

Of the 25 native trout species and subspecies in the contiguous U.S.:



Sensitive (23) Trout facing one or more threats are designated as sensitive and need conservation attention to prevent decline.

Protected (6) The Endangered Species Act protects six of these sensitive trout.

Not sensitive (2) Only two types of trout are not considered sensitive.

Extinct (3) Experts believe three types of trout have become extinct since the 1800s.

CHRISTINA SHINTANI, NGM STAFF. SOURCES: TROUT UNLIMITED SCIENCE; DONOVAN BELL AND OTHERS, *SCIENCE ADVANCES*, DECEMBER 2021; BERNHARD LEHNER AND GÜNTHER GRILL, HYDRORIVERS

Top five threats
Climate changes affects trout in varying ways. All native trout are moderately vulnerable to at least one risk factor; most are facing multiple threats.

Climate change risk factors

Selected native trout	Warming water	Low water levels	Flooding	Wildfire	Invasive species	
Bull trout *Salvelinus confluentus*	🔴	🔴	🔴	🔴	🟡	🐟
Coastal cutthroat *Oncorhynchus clarkii clarkii*	🟡	🟡	🟡	🟡	🔵	
California golden *O. mykiss aguabonita*	🟡	🔴	🟡	🔴	🔴	
Lahontan cutthroat *O. clarkii henshawi*	🔴	🔴	🟡	🔴	🔴	🐟
Columbia River redband *O. mykiss gairdnerii*	🔴	🔴	🔵	🔴	🔴	
Klamath headwaters redband *O. mykiss newberrii*	🔴	🔴	🔵	🔴	🔴	
Westslope cutthroat *O. clarkii lewisi*	🟡	🟡	🟡	🔴	🔴	
Yellowstone cutthroat *O. clarkii bouvieri*	🟡	🟡	🟡	🔴	🔴	
Gila and Apache *O. gilae and O. apache*	🔴	🔴	🟡	🔴	🔴	🐟
Lake trout *Salvelinus namaycush*	🟡	🔵	🔵	🔵	🔴	
Brook trout *Salvelinus fontinalis*	🟡	🔵	🟡	🔵	🔴	Great Lakes and upper Mississippi
	🟡	🔵	🔴	🔵	🟡	Northeast
	🔴	🔴	🔴	🔵	🔴	Southeast

Vulnerability level

🔴 High
🟡 Moderate
🔵 Low
🐟 Protected species

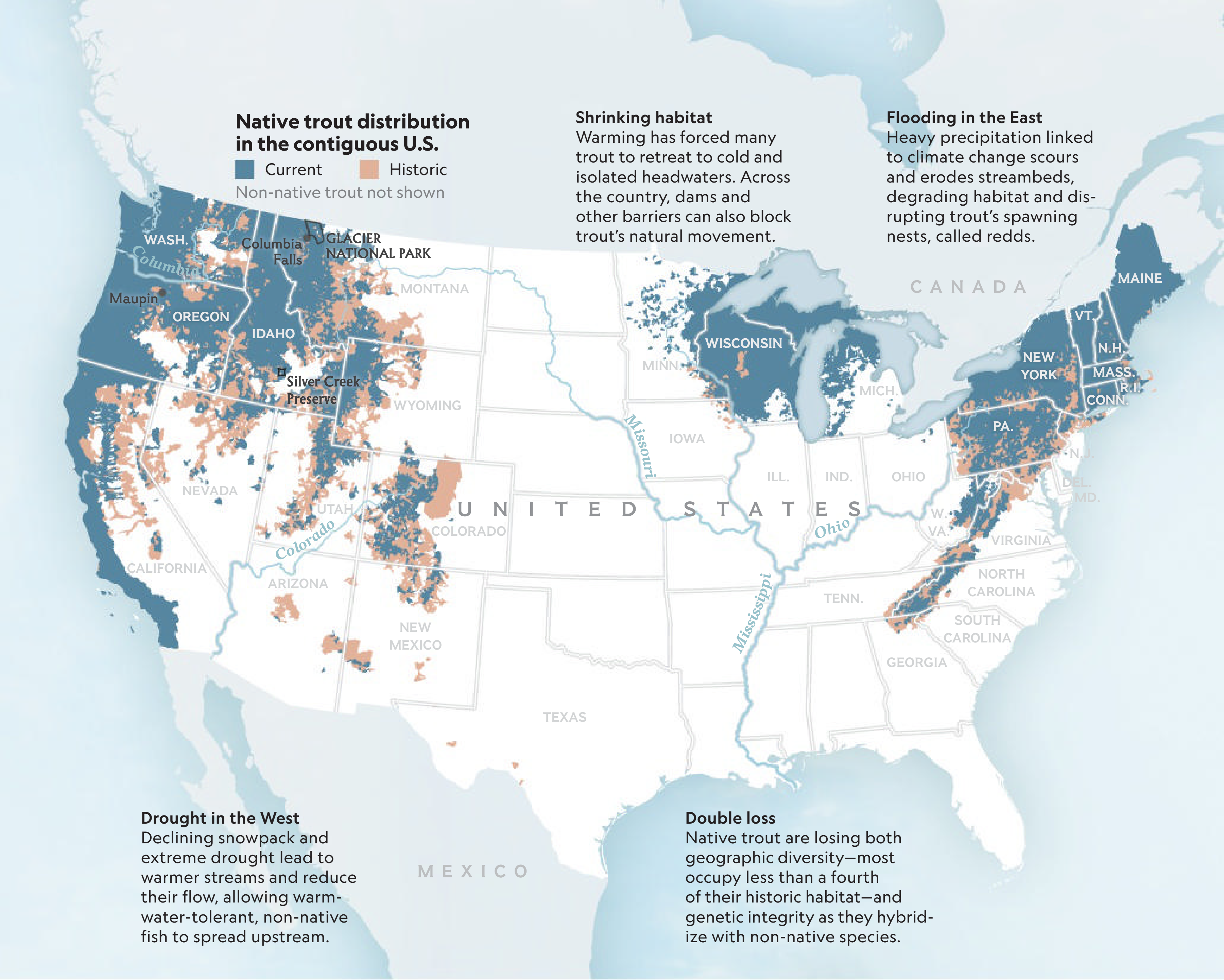
But change has come to the Middle Fork. The glaciers and snowpack in nearby Glacier National Park, which feed cold, clear water into the river all summer long, are dwindling. The patterns of water flows are changing. Clients catch more hybrid fish than in the past. All this was evident already in 2019, when I spent time with Hutcheson—but last summer turned into one of the toughest yet on cold-water fish in the West. States from California to Montana had seen skimpy snows erased by a warm, dry spring. Many places then got record heat in late June. Fish suffered.

In Idaho, low water and high temperatures caused managers to close the Silver Creek Preserve, a world-famous trout fishery where Ernest Hemingway fished. In Montana, "hoot owl" restrictions, which forbid fishing from 2 p.m. to midnight, were ordered on world-class trout rivers to relieve fish from the stress of being caught and released in the hottest hours.

On the Flathead, one of the gravest threats posed by climate change to fish is genetic: Introduced fish are mating with native cutthroat trout, a mixing that has been abetted by changing water flows. If left unchecked, this could wipe out the cutthroat population, devastating a cherished American fishery.

When we talk of the climate crisis, we often focus on cataclysm—melting Greenland, or a Denver suburb aflame in December. Overshadowed are the subtler changes to our daily lives. One such change is the warming of cold-water lakes, rivers, and streams around the world. As these waters heat up, many fish will be in trouble. Which means fishing will be in trouble too. The changes are already under way.

To some this might seem picayune. But fishing has never been simply a pastime. Fishing is summer camp. It's Saturday with your buddy or your



Native trout distribution in the contiguous U.S.

🟦 Current 🟧 Historic

Non-native trout not shown

Shrinking habitat
Warming has forced many trout to retreat to cold and isolated headwaters. Across the country, dams and other barriers can also block trout's natural movement.

Flooding in the East
Heavy precipitation linked to climate change scours and erodes streambeds, degrading habitat and disrupting trout's spawning nests, called redds.

Drought in the West
Declining snowpack and extreme drought lead to warmer streams and reduce their flow, allowing warm-water-tolerant, non-native fish to spread upstream.

Double loss
Native trout are losing both geographic diversity—most occupy less than a fourth of their historic habitat—and genetic integrity as they hybridize with non-native species.

daughter. For millions of people, fishing is a way to grasp the wriggling natural world in your hand. In many families, fishing is art passed down as heirloom, a tradition fashioned of wisdom and bound with 10-pound test line and a Palomar knot. "Now I know," Ota Pavel wrote in his sad, perfect memoir *How I Came to Know Fish*, "that many who fish do not go out for the fish alone."

There are many ways to catch a fish. Hutcheson is a fly-fisher, which is arguably the most elegant kind and also the most ridiculous. Fly-fishers attempt to dupe a fish by tossing an artificial insect the size of pocket lint appetizingly upon the water, in just the right spot, using casts that take years to perfect and a second to bollix up. Fly-fishing favors obsessives, or else it creates them. By its nature, as writer Norman Maclean pointed out, it reminds us of our flaws but occasionally allows us to draw close to grace.

On the river that morning, Hutcheson said not to worry about those hybridized fish. We were upstream enough on the Middle Fork that we shouldn't see any. I cast. The first fish I brought to hand was a mutt.

The second fish was too.

So was the third.

AROUND THE WORLD, more people fish for fun than for a living—at least 200 million in developed countries alone. Americans are particularly passionate: About one in six grabbed a fishing rod in 2021. Most headed to freshwater—the nation's lakes, rivers, and streams. Fishing inland waters for recreation props up the economies of entire small towns like Ennis, Montana, and Maupin, Oregon, generating about $30 billion in direct spending alone in the United States each year.

Worldwide, though, freshwater fish went extinct twice as fast as other vertebrates during the 20th century. In North America almost 40 percent of inland fish are imperiled, a 2008 survey found—at 700 species, nearly double the number from just 20 years earlier. Why? We have bulldozed rivers and made them run as straight as aqueducts. We have logged mountainsides, paved riversides, and built homes there, sending silt and pollution into streams. We have introduced fish from elsewhere that outcompete the locals.

And now comes climate change to land yet another blow, like a roundhouse to a battered boxer.

Climate change is hitting many inland fish hard, directly and indirectly. As air temperatures rise, rivers and streams warm. Sometimes waters become too hot for fish to tolerate, or the warmth makes them susceptible to illness or pathogens.

In the U.S. and elsewhere, winter snow in the mountains, snow that feeds rivers and streams the rest of the year, is giving way to rain that runs off right away. Snow arrives later in winter and often melts earlier in spring; in the northern Rockies, where Hutcheson lives, peak snowmelt has recently occurred weeks earlier than it used to. Less water in a river means less room for fish to live, which limits their population. Across the country, but especially in the Northeast and Midwest, there's another problem: Much more rain now falls during heavy downpours. These rains scour streams of eggs and young fish.

So-called game fish that rely on cooler freshwater—walleyes, trout, salmon, whitefish, to name some of the most popular—are particularly squeezed. Consider the brook trout, with its olive back scribbled with runes and sides freckled with haloed dots. "Brookies" are frequently said to be our nation's loveliest fish. Anglers pursue them in the coldest, cleanest streams of the East and upper Midwest, their native range. But in Wisconsin, brook trout are projected to disappear around 2050 from nearly 70 percent of the 21,000 miles of rivers and streams where they now swim. In the southern Appalachians, brook trout will retreat ever higher up the mountains, keeping to the coldest water, until they run out of mountains altogether. In time, Virginia may lose its state fish.

Walleyes are one of the most popular sport fish in Wisconsin; by 2090 they'll be unable to sustain themselves in a third to three-quarters of the lakes in the state that now hold them. Even rainbow trout, one of the most commonly stocked fish, could see its usable waters decline substantially in the Midwest and in the West too.

HUTCHESON STILL recalls the day a friend's uncle put a fly rod in her hand when she was a girl, and she caught her first cutthroat trout on the Middle Fork. Soon she and her sister taught themselves to fly-fish. Then, in 1992, the film *A River Runs Through It* appeared, based on Maclean's classic novella of Montana fishing and family ties. The country went crazy for fly-fishing, or at least for a young Brad Pitt in a wet shirt. The sisters became among the first female fishing guides in the area.

Today Hutcheson owns a fly shop in Columbia Falls, Montana, the riverside town where she grew up. She writes about fishing, often with a conservation bent. She works as a guide about 120 days a year and fishes professionally all over the world. But wherever she goes, she told me, she always looks forward to coming home and fishing for cutthroat.

"Cutties" are a special fish, she said. "They pull, they fight, they run."

Given how many anglers are seeing their favorite fishing holes affected, you might expect more of an outcry from them about climate change. It's happening, but for many it was slow to develop. Hutcheson had been paying attention to the issue since college. As a young guide, she grew frustrated by the changes she was seeing on the river and by politicians' inaction. Start showing influential people these places and speaking up, her siblings told her. She listened.

"Somebody else isn't going to do it," she told me. "We are 'they.'"

Hutcheson's been to Washington, D.C., several

Kalispell, Montana, is a gateway to Glacier National Park and to some of the best fly-fishing in the world, on the Flathead River. Outdoor recreation pumps about $2 billion a year into Montana's economy. Rainbow trout are plentiful in the state's rivers—but they're non-natives, introduced by people.

Rainbow
BAR
Cocktails
CASINO
SOUTH
35

times to lobby Congress and the White House for Protect Our Winters, a group of more than 200 professional athletes, artists, and others whose work is affected by climate change. She talks about changes she sees on the rivers—and the effect on her hometown. "I care about humans who will lose their jobs, their livelihoods, and their fundamental happiness as this system collapses," she told a congressional panel in 2019.

The year before, massive wildfires had torn through Glacier National Park and the surrounding area, keeping Hutcheson off the river for nine days. "When we get shut down during fire season, at the height of my fly-fishing season, I can lose a winter's worth of groceries for my family," she told me. The main businesses in her town that still thrive during times like those, Hutcheson says, are places that sell liquor.

SUCH CONCERNS LED her to the work of Clint Muhlfeld—and to an indirect way that climate change is threatening her beloved river and its native species. Muhlfeld is an aquatic ecologist for the U.S. Geological Survey, in western Montana. As the mercury climbed toward the 90s one day, he, Hutcheson, and I drove to the North Fork of the Flathead, on the western boundary of Glacier.

Peering into an Oregon creek, "super excited to get into the headspace of a beaver," Northwest Youth Corps member Hannah Clifford builds a faux beaver dam near the Grande Ronde River. The Trout Unlimited program aims to slow the flow of water in the creek to attract spawning salmon and steelhead trout.

The North Fork courses here through a wide, cobbled floodplain, tracing a new path each spring. In the distance, Glacier's chipped teeth still were piebald with snow in midsummer. Muhlfeld, a lean, excitable man with a tattoo of a bull trout on one ankle, stood in the bow of the raft, clutching a fly rod.

"We're at the invasion front, right here," he said, as Hutcheson pushed off.

Over decades, people stocked roughly 200 million rainbow trout in Montana's rivers and lakes, including 20 million in the Flathead River system. Fish were stocked all over the West to buoy the sport fishery, often simply dumped from railroad cars banging across the country. Rainbow trout, which are primarily native to coastal streams of the northern Pacific Rim, leap high when hooked, and they taste good, and even today many anglers enjoy bagging them. But there's a problem: They reproduce with all 12 subspecies of cutthroat trout, most of which, like the westslope cutties in the Flathead, are native to the interior waters of the West. Today cutties occupy less than 10 percent of their historical habitat. That habitat loss and hybridization are the main reasons they're struggling.

The U.S. Fish and Wildlife Service has declined to designate westslope cutthroat as an endangered species, declaring that a cutthroat with up to 20 percent rainbow genes is still a cutthroat. Muhlfeld and colleagues decided to test that assumption. Their results shocked them: If a cuttie contains just 20 percent rainbow genes, the trout's "fitness," as measured by the survival of its offspring, is reduced by at least half.

As the boat drifted, I caught a modest fish on the fly. Hutcheson scooped it into the net and showed it to Muhlfeld. He pointed out the vibrant slash under the jaw, the rosy belly that indicated the fish had spawned this year, and the dense spots above its lateral line, a sense organ that runs the length of its body.

"*Oncorhynchus clarkii lewisi,*" he said appreciatively. "That fish right there is likely a genetically pure cutthroat trout." It has the genes, the adapted traits, that make it perfectly suited to survive and persist here, as it has done since the last ice age. As a species, cutthroat trout have survived periods even warmer than today.

"Beautiful fish," Muhlfeld said, handing it back to the river.

Later I landed another fish. Muhlfeld peered into the net. His tone changed. He pointed out

Aquatic ecologist Clint Muhlfeld studies westslope cutthroat trout in the Flathead River. He's found that climate change is helping rainbow trout spread upstream and hybridize with the native cutthroat. In the hybrids, "you see a dramatic decline in fitness," he says. "So that's a major concern."

how the slash beneath the jaw was fainter and how the spots appeared both above and below its lateral line. “Probably a low-level hybrid,” he said—a cutthroat with a dash of rainbow.

Hybridization is a problem both for fish and for fishing, he said. Rainbow trout are roughly equivalent to factory-farmed chicken. When they breed with native cutthroat, they adulterate thousands of years of wild genetic wisdom. The mongrel fish aren’t as suited to their environment or as nimble at adapting to change.

For many years the problem was more or less contained. Rainbow trout largely stayed where they were introduced in the lower reaches of the Flathead system. They spawn earlier in the spring than cutthroat do, and high spring runoff would wash away their eggs, scientists think.

But climate change has tinkered with that equation. More frequent times of low water seem to be permitting introduced rainbow trout to spread farther upriver and breed more often with native fish. In one area, the amount of gene-swapping increased tenfold over the past 30 years, Muhlfeld and colleagues found. Rainbows are “ticking time bombs waiting to go off, under the right environmental conditions,” Muhlfeld said.

In the early 2000s, when the Flathead saw some dramatically lower spring flows, hybridization appeared to surge. Years like those, once outliers, are projected to become more common as climate changes—each delivering a fresh injection of less-fit hybrids.

Simply put, these inferior fish will find it harder to survive. There may be fewer fish in the river, Muhlfeld said. And these “cut-bows” are not as feisty and as fun to catch, Hutcheson added.

None of this is good for those who love fish and fishing, she said. She plopped the fish I’d caught back into the river.

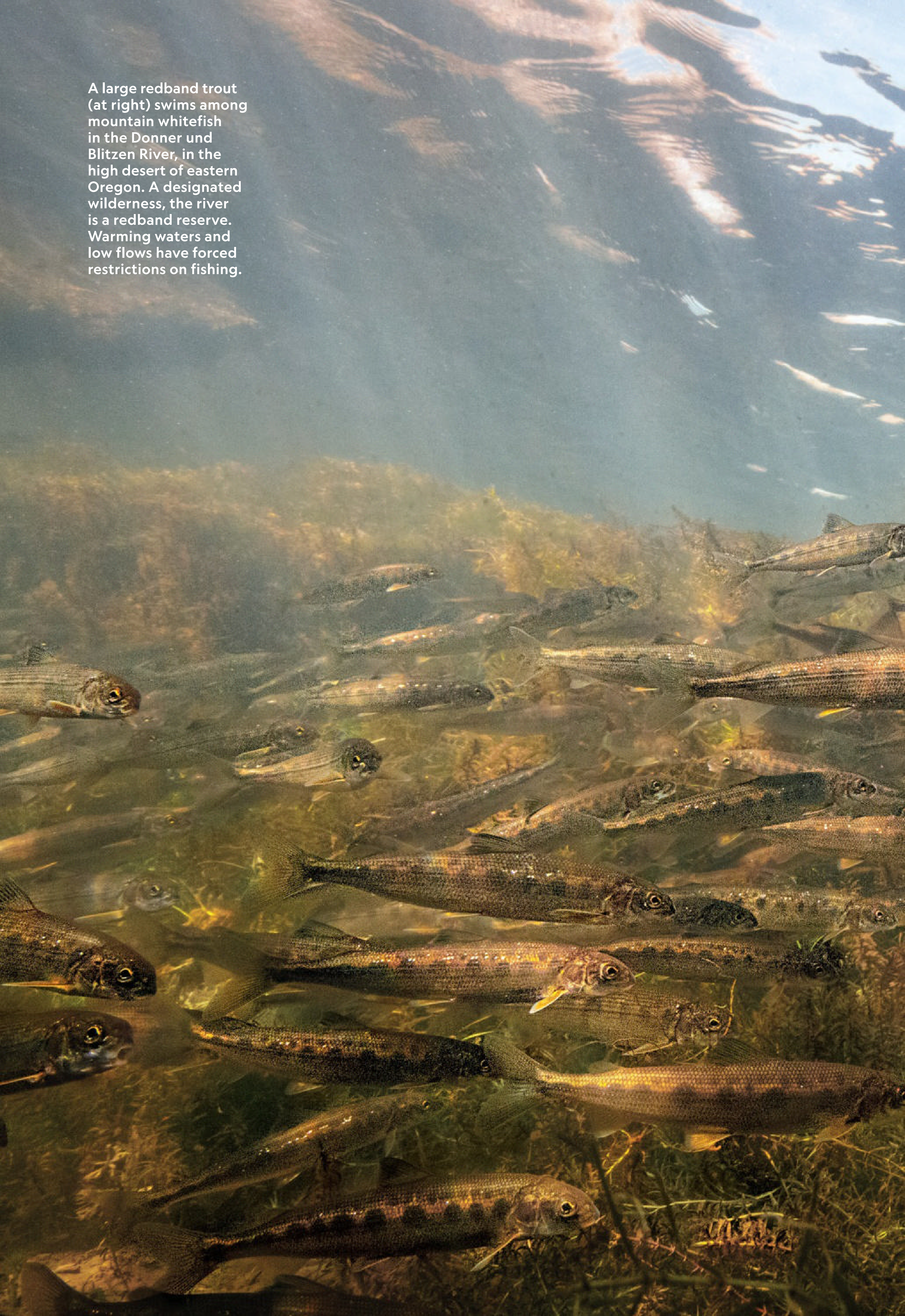
FISHING WILL NOT END as lakes and rivers warm. The sport will suffer severely in places, though, and will look very different in others. As fish such as trout retreat, they often will be supplanted by smallmouth bass or other species that can tolerate warmer water. “It’s still a fish you can fish for,” Robert Al-Chokhachy, a research fisheries biologist with the U.S. Geological Survey, told me

Joseph Metzler, a retired Coast Guard rescue swimmer, spearfishes in Oregon’s Coquille River for smallmouth bass—an introduced species that competes with native fish and recently was declared fair game. The bass thrive in warming waters.

with a shrug. But being more common and widespread, those species may not attract as many people to a place or as much revenue. And there's another kind of loss when native fish are replaced by ones that could be found most anywhere: It makes for a grayer, more impoverished world, where everyplace is more like anyplace else.

In *Fishing Through the Apocalypse*, writer and conservationist Matthew Miller cautions readers not to overromanticize the pastime they think they know. That rainbow trout arcing over a pluperfect Montana scene in *A River Runs Through It*? Humans put that trout there. In most places, fishing hasn't been an unsullied wilderness experience for a long time. When some anglers today sit at their computer, hitting the refresh button, waiting to find out when a tanker truck from the state wildlife agency will back up to their local lake and dump a load of hatchery-raised fish—this too is fishing. And this too is communion with nature. It may become more common in the future.

Many scientists I spoke with offered surprising optimism—not about our ability to stop climate change but about the things we can do to help cold-water fish survive. In the Flathead River system, for example, aggressive moves by tribal, state, and federal governments to beat back introduced fish so far have kept the threat in check, Muhlfeld said. In addition to eradicating nonnative and hybrid fish directly, workers have dug up rainbow trout redds, or spawning beds, in



A large redband trout (at right) swims among mountain whitefish in the Donner und Blitzen River, in the high desert of eastern Oregon. A designated wilderness, the river is a redband reserve. Warming waters and low flows have forced restrictions on fishing.

creeks; they've placed barriers in some creeks to protect pure fish from intruders. The downside of such work is that it may have to be done forever.

Theoretically it's also possible to cool down streams and rivers, even as air temperatures rise. The John Day River in northeast Oregon is home to the biggest wild run of Chinook salmon, a threatened species, in the Columbia River Basin. Clearing of forest that once lined the riverbanks has been the major reason the John Day's waters have warmed, allowing smallmouth bass to invade the upper watershed. By century's end they could eliminate the Chinook there.

But in a 2019 study, scientists estimated that shading 23 miles of the upper river with mature native forest would lower the average daily high temperature of the water a startling 10 to 12 degrees Fahrenheit. Of course, you'd need to plant 23 miles of forest, then wait many years for the shade. Such reforestation projects are under way, though, on the John Day and across the West.

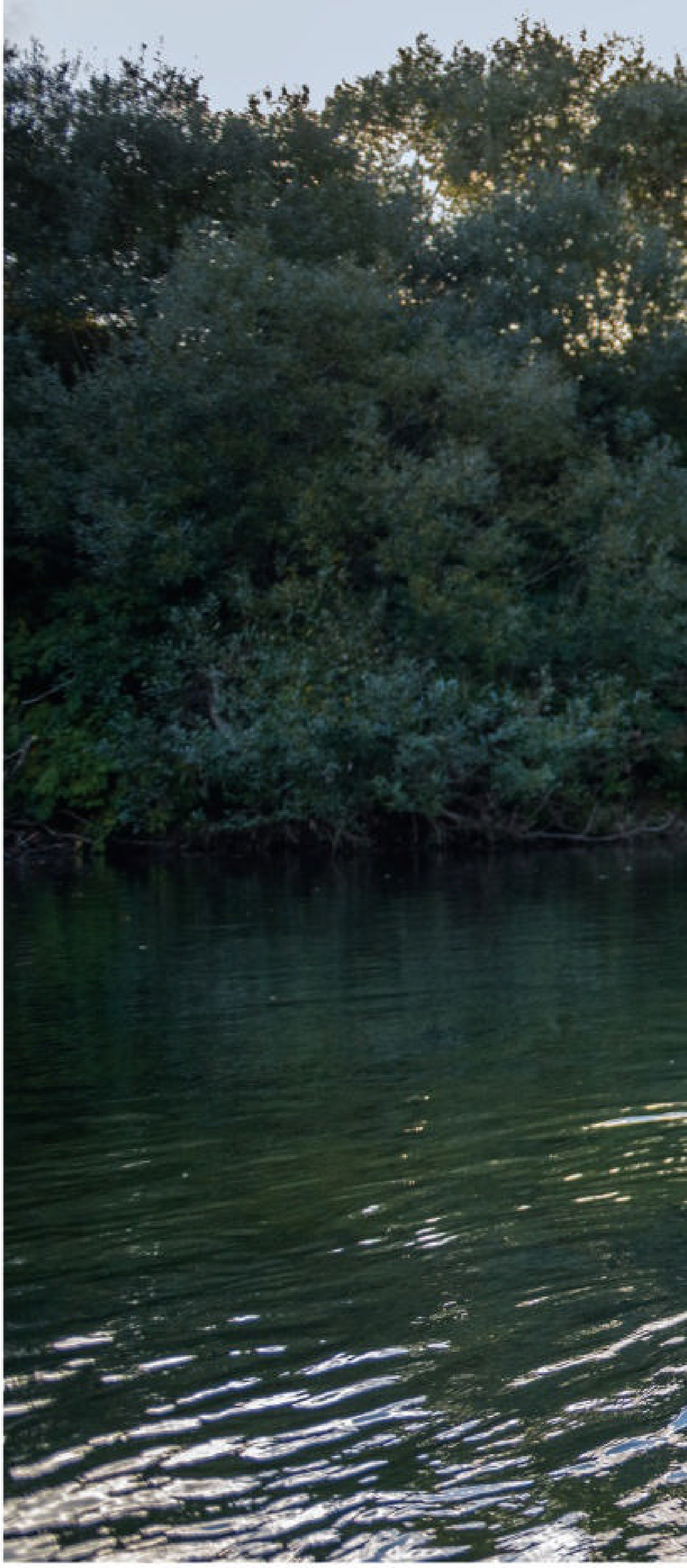
"We have solved conservation issues that have seemed intractable," said Miller, who works at the Nature Conservancy. "The issue is that we often wait till things get really bad and then try these last-ditch efforts."

There's another reason for some hope: Models that predict a bleak future for inland fish do not account for the possibility that fish could adapt to a changing world. A 2011 study of sockeye salmon from eight populations in British Columbia migrating up to 700 miles in the Fraser River system found that even though the sockeye looked identical, the fish have developed adaptations to undertake migrations of wildly different lengths, intensities, and water temperatures.

"This shows us that within a species, different populations can adapt to their specific conditions," said lead author Erika Eliason, a zoologist now at the University of California, Santa Barbara.

If we can buy time for fish, perhaps they can adapt and persevere in this new world humans are creating. Sometimes they may need a helping hand: Muhlfeld and colleagues have been putting imperiled bull trout in backpacks and carrying them to higher altitudes in Glacier, to help them find cooler waters they can't reach on their own.

More often, though, we can help fish by keeping their homes as unchanged as possible. We know what Flathead cutthroats need, for example: "Cold, clean, complex, and connected habitats," Muhlfeld said. The "connected" part is crucial. Middle Fork cutthroats are kissing



Justin Futch and son Zade of the Coquille Indian Tribe spearfish for smallmouth bass on the Coquille River. Futch, who carved the canoe himself, fishes to feed his family and to feel his heritage. "The river is at the heart of the Coquille people," says tribe biologist Helena Linnell.

cousins to North Fork ones, yet genetically distinct. Any of them might hold the genetic wisdom to help the species do well in the future—as long as the river still allows them to persist and mix.

Faced with weekly headlines about another catastrophe, the loss of a favorite fishing hole—or even a fish in a river—may not seem to rate. But it's no small thing that this too is the world we're making: a world that erodes, and sometimes erases, the simple pleasures that give us respite, make us smile, and brighten the days with silver shards of beauty. A ski through deep snow. Ice-skating on an open lake. Gardening. Bird-watching. Fishing.

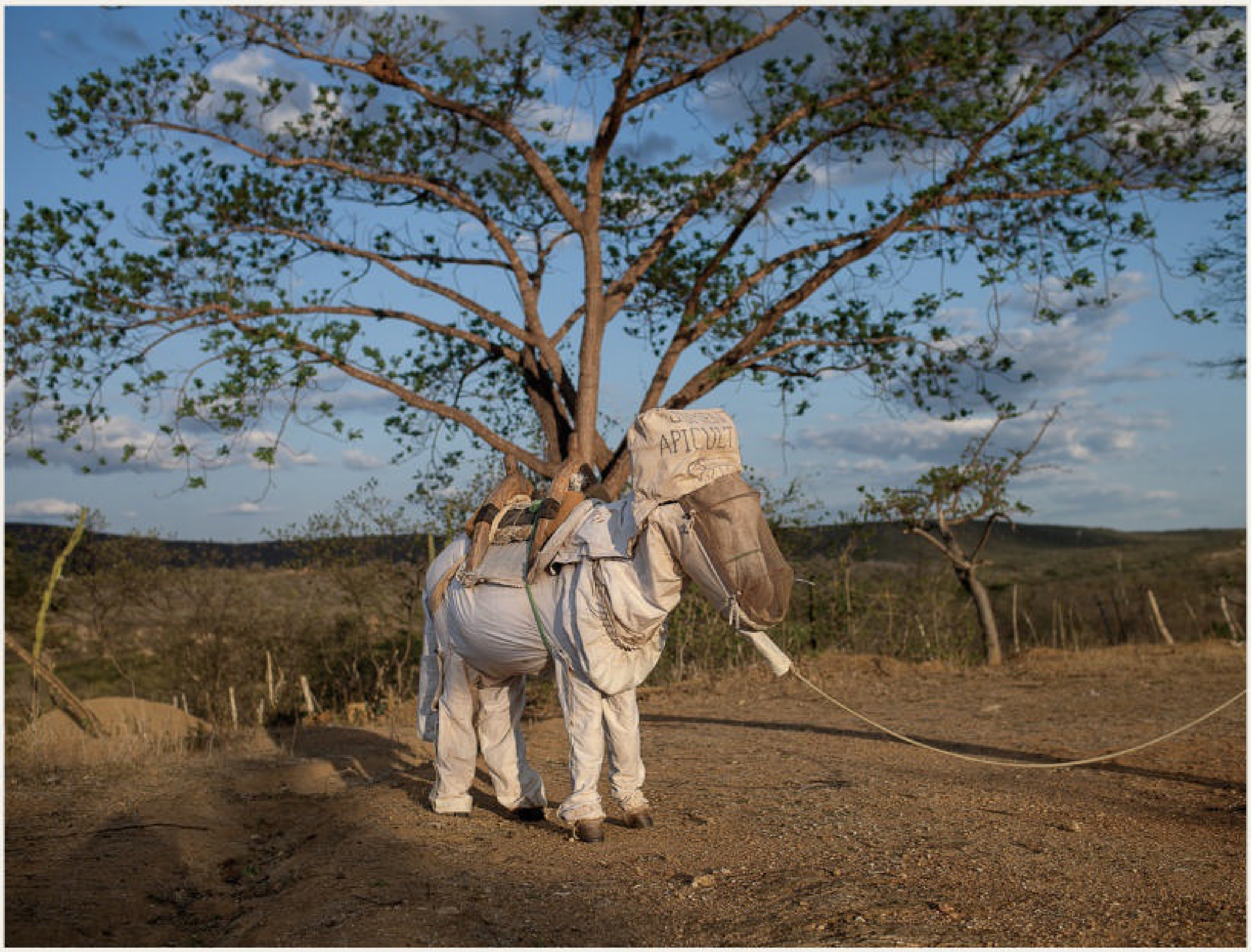
As we drifted down the river one day, I asked Hutcheson whether she despaired, knowing how bad things might yet get. She waved me off. Mourning was what you do over the dead. There was still time. Her job now was to get people to act.

"We still try. We try, try, try," she said. "We're alive right now, and for me, being alive is to try."

If fishing is anything, it's the relentless practice of hope. It's the belief that no matter how much we've fallen short, next time we'll do better.

Hutcheson tied a new fly onto the tippet of my line. She raised the anchor, took the oars again, and returned us to the embrace of the river. She told me to cast. ☐

Writer **Christopher Solomon** lives and fishes near his favorite trout run in eastern Washington State. Photographer and filmmaker **Kholood Eid** lives in New York City. This is her first work underwater.



INSTAGRAM

NADIA SHIRA COHEN

FROM OUR PHOTOGRAPHERS

WHO

A Rome-based photojournalist focused on the stories of people and places

WHERE

Outside Itatira, in the Brazilian state of Ceará

WHAT

Canon EOS 5D Mark II with a 35mm lens

For centuries, donkeys helped develop northeast Brazil, hauling water, crops, and building materials. Urbanization led to out-of-work donkeys, thousands of which were slaughtered and their hides sent to China, where they're used in traditional medicine. In February a federal regional court granted the donkeys a stay of execution. While covering this long-simmering story in 2015, Cohen heard about Boneco, above, whose inventive owner repurposed him as a beekeeper's assistant, complete with custom-made uniform.

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Above: Mount Kenya rises behind a group of reticulated giraffes.

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A ONE-OF-A-KIND JOURNEY AROUND THE WORLD

In this inspiring travelogue, celebrated traveler and photographer Jessica Nabongo, the first Black woman on record to visit every country in the world, shares her journey around the globe with fascinating stories of adventure, culture, travel musts, and human connections.

Along with stories from beloved destinations like Peru and South Africa, you'll also find tales from far-flung corners and seldom visited destinations, including Tuvalu, North Korea, South Sudan, and the Central African Republic. Nabongo's stories are love letters to diversity, beauty, and culture—and most of all, to the people she meets along the way.

JESSICA NABONGO is a writer, photographer, entrepreneur, travel expert, influencer, and public speaker. She completed her journey as the first Black woman on record to travel to all 195 countries of the world in October of 2019. At her core, she is a dreamer looking to craft a life and career that connects her passions and talents. She wants to use her story to educate and inspire others to travel and experience the world around them. She uses her blog, The Catch Me If You Can, to share her travel adventures and build a global community.

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